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## Application of Forced Drainage Attenuation Constants

By M. E. Parker, Jr.

Pan American Pipe Line Company, Houston, Texas

THE ARTICLE, "Attenuation of Forced Drainage Effects on Long Uniform Structures," by Mr. Robert Pope, in the December, 1946, issue of CORROSION presents a set of equations expressing the attenuation of the three quantities  $V_x$ , change in structure/soil potential;  $I_x$ , current on structure; and  $i_x$ , cathodic current density, as functions of the distance  $X$  along the structure from the drainage point. The three equations are functionally identical:

$$V_x = V_o e^{-\alpha x} \text{ volts} \quad [6]$$

$$I_x = I_o e^{-\alpha x} \text{ amperes} \quad [8]$$

$$i_x = i_o e^{-\alpha x} \text{ milliamperes per square foot} \quad [9a]$$

[The equations are numbered to correspond to Mr. Pope's article; No. 9a is a combination of his No. 9 and No. 11.]

For a given structure in a given environment, the characteristic attenuation constant,  $\alpha$ , is a function of the physical constants of the structure and its environment:

$$\alpha = \sqrt{R_s / R_L} \text{ per kilofoot} \quad [3]$$

$$\alpha = R_s / R_K \text{ per kilofoot} \quad [4]$$

These constants are connected by the relations

$$R_K = \sqrt{R_s R_L} \text{ ohms} \quad [2]$$

$$R_K = 2 R_o \text{ ohms} \quad [1]$$

All of these relationships are based on the assumption that conditions are uniform along the length of the structure; i.e.,  $R_s$ ,  $R_L$ , and  $\rho$ , and hence  $R_K$  are uniform throughout the section under study. It is unnecessary to point out that this is never the case in practice. Not only is there a great deal of variation in these quantities, but the determination of any kind of reasonable average by direct measurement is difficult.

This does not mean, however, that these equations are not useful. On the contrary, their usefulness springs very largely from the difficulty of measuring these quantities directly. The equation gives us an excellent picture of the *form* of the relationship connecting the constants with the drainage effects, and some of the latter are easily measured. This is particularly true of  $V_x$ , the change in structure/soil potential produced

by the application of cathodic protection. The use of this quantity is illustrated by the following example.

A rectifier is draining 25 amperes from a pipeline into an anode bed located 500 feet from the line. The pipe is 12 $\frac{3}{4}$ " O.D., and has an asphalt enamel coating, with a single bonded wrap of asphalt saturated felt. The terrain traversed is hilly, with two swampy river bottoms and numerous creeks. Soil resistivity [measured at the surface] ranges from 1.5 to over 300 meterohms. The line was originally laid in very bad weather and under hurried conditions, so there is good reason to suspect a less than perfect coating job.

The rectifier was, at the time of these measurements, alone on a 60-mile section, being located a mile from one [insulated] end; thus the current division in the two directions from the drainage point is unequal.

The pipe/soil potential was measured with a copper sulfate electrode at six points, as tabulated below.

Point	Dist. from Drain Pt. kilofeet	P/S Pot. Before volts	P/S Pot. After volts	V <sub>x</sub> volts
1	0.0	0.800	2.450	1.650
2	26.56	0.336	0.769	0.433
3	64.43	0.860	0.980	0.128
4	94.94	0.713	0.746	0.033
5	150.65	0.594	0.598	0.004
6	195.23	0.600	0.600	0.000

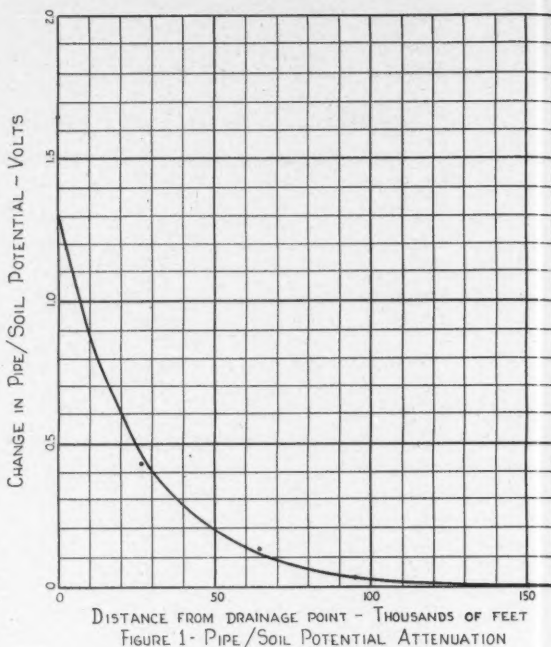


FIGURE 1—PIPE/SOIL POTENTIAL ATTENUATION

The value of 1.650 cannot be used as  $V_0$  in the attenuation equation, since, as explained in Mr. Pope's article, it must be considered as the sum of two effects. The last point, with an indicated value of zero for  $V_x$ , we cannot use in the equation, due to mathematical difficulties.

From the other four values, however, we may derive our constants. Writing equation [6] in logarithmic form,

$$\log_{10} V_x = \log_{10} V_0 - \alpha X \log_{10} e \quad [12a]$$

Substituting the values of  $X$  and  $V_x$  for points 2—5,

$$[2] \quad -0.3635 = \log V_0 - 11.535\alpha$$

$$[3] \quad -0.8928 = \log V_0 - 27.981\alpha$$

$$[4] \quad -1.4815 = \log V_0 - 41.231\alpha$$

$$[5] \quad -2.3979 = \log V_0 - 65.426\alpha$$

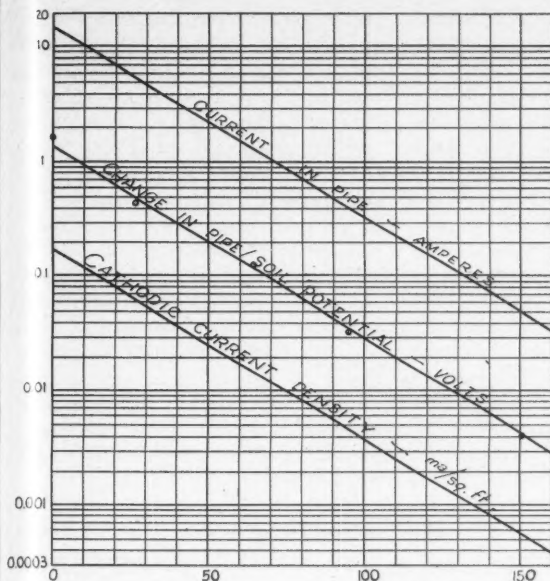


FIGURE 2 - ATTENUATION CURVES

We now have four equations in two unknowns. If the facts agreed perfectly with theory, any pair of these equations would give the same values for  $V_o$  and  $\alpha$  when solved. This not being the case, we must apply the method of Least Squares [a very useful but much neglected technique] to obtain

$$\alpha = 0.0382 \text{ per kilofeet}$$

$$\log V_o = 0.1135, \text{ volt } V_o = 1.299 \text{ volt}$$

The attenuation equation for potential is then

$$V_x = 1.299 e^{-0.0382 x}$$

This equation is shown in Figure 1, with the measured values indicated by small circles. Remembering that the first point is influenced by anode proximity, it is seen that

the agreement with the theoretical form of the function is very good. In Figure 2, the same equation is shown on semi-log paper, where it appears as a straight line.

Equations [6], [8], and [9a] show that all three attenuation equations have the same slope, so we need only one point for each of the other two.

Measurements of the potential drops in short sections of the pipe on either side of the drainage point indicate that approximately 60 per-

cent of the current is being drawn from the "long" direction. This corresponds to a value of  $I_o = 15$  amperes, which was used in the curve in Figure 2. We may also use the equation

$$i_o = \frac{12 I_o \alpha}{\pi d} \text{ milliamperes per square foot}$$

to determine the cathodic current density,

$$i_o = 0.171 \text{ ma/sq. ft.,}$$

and thus obtain the third curve of Figure 2.

The quantity  $R_s$  is a known function of the pipe itself, and enables us to compute the leakage resistance by means of equation [3]:

$$R_L = R_s / \alpha^2 = \frac{0.00354}{0.00131} = 2.703 \text{ kilofeet-ohm.}$$

This value discloses that the coating is not very good [thus confirming experience and inspection].

An interesting comparison may be made between some of the various accepted criteria for protection. The assumption that the line is 2 percent bare, and that 2 ma/sq. ft. of exposed pipe is required for protection, leads to a limit of protection at the point where the gross density is  $0.02 \times 2 = 0.04$  ma/sq. ft. This point is reached at  $X = 40,000$  feet. It may be noted that the potential change at this point is 0.290 volt, as compared with the frequently used criterion of 0.3 volt.

It is a property of exponential functions of the type here employed, that any point of the curve may be taken as an initial point. Thus that portion of the three curves in Figure 2 lying to the right of  $X = 50,000$

feet represent the values we should have on a similar pipe with a rectifier [or a galvanic anode] at that point drawing from one direction a current of 2.3 amperes. This characteristic makes it possible to plot the attenuation curves for a composite line—one composed of sections of different size pipe [variation in  $R_s$ ], different coating or different soil [variation in  $R_L$ ], or a line having laterals [discontinuous variations in  $I_x$  and  $i_x$ , but *not* in  $V_x$  at the intersection of the lateral.] Some of the effects may be computed, others might be determined by field measurements, at critical points, of  $I_x$  or of  $R_G$ , followed by the necessary computations.

The writer wishes to thank the management of the Pan American Pipe Line Company for their permission to publish these data.

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## Discussion

*By Robert Pope*

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Mr. M. E. Parker's application of the attenuation formulas to a practical case is very interesting, particularly because the measured points come very close to his calculated curve, even though the pipeline traversed soils of widely different resistivities. We have observed similarly close adherence to the theoret-

ical values on our underground cables, but have not encountered such wide variations in soil characteristics as Mr. Parker describes.

His remark that the drainage point was located relatively close to the end of the pipeline raises the question of the effect of a termination on structure-to-soil resistance.

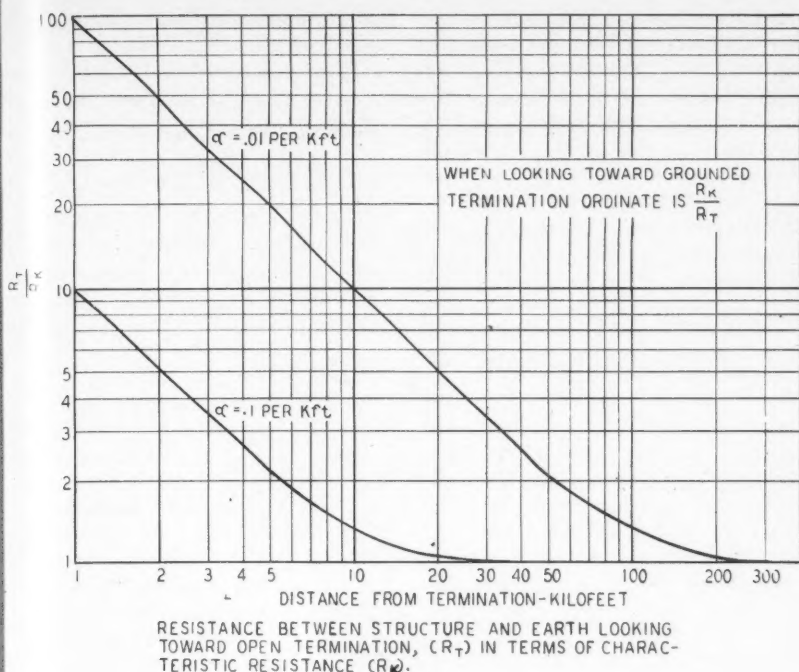


FIGURE 1

This resistance looking toward the termination is expressed by the equation:

$$R_T = R_K \frac{1 + K e^{-2\alpha x}}{1 - K e^{-2\alpha x}}$$

where

$$K = \frac{R_1 - R_K}{R_1 + R_K}$$

and  $R_1$  is the terminating resistance and  $x$  is the distance in kilofeet to the termination.

If conditions change, such as a reduction in the size of the structure,  $R_1$  may be the characteristic resistance of the changed structure. If the termination is electrically "open," a condition approached by an insulating joint,  $R_1 = \infty$  and  $K = 1$ . If the termination is a "solid ground" ap-

proached by a large underground network,  $R_1 = 0$  and  $K = -1$ . If  $R_1 = R_K$ ,  $K = 0$  and  $R_T = R_K$ . The chart, Figure 1, shows the resistance looking toward an open termination for two values of α. When α = 0.1 per kilofeet, the resistance looking toward the termination becomes essentially equal to the characteristic resistance at about 15 kilofeet. These curves can also be used to show the resistance looking toward a ground

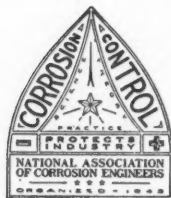
and by making the ordinate  $\frac{R_T}{R_K}$ .

For a termination of a given resistance in terms of  $R_K$ , the abscissa for that value can be considered as 0 distance, and the curves can still be used. For example, if the termi-

nating resistance is  $5R_K$  and  $\alpha = 0.1$  per kilofoot, the 2 kilofoot abscissa becomes 0 because the curve crosses  $5R_K$  there, the 3 kilofoot abscissa becomes 1, 4 becomes 2, 10 becomes 8, etc. On the basis of the revised abscissa values, the resistance of structure to earth looking toward the termination can be determined for any distance from the termination. When computed in parallel, with the structure to earth resistance looking in the opposite direction (which is  $R_K$  when remote from the other ter-

mination) the actual structure-to-earth resistance is obtained.

These computed resistance values have been used in testing leakage resistance of buried thermoplastic covered cables where a minimum resistance of 100 kilofoot-ohms was to be maintained. The "bogey" resistance was computed in this manner and the coating was considered to be in satisfactory condition where the measured resistance exceeded this bogey.



## Use of Corrosion Inhibitors in Products Pipelines—A Survey of Practices\*

By Dr. Ivy M. Parker\*

Plantation Pipe Line Company, Atlanta, Georgia

**T**HE PRACTICE OF USING corrosion inhibitors in products pipelines during the past ten years has saved the oil industry many thousands of dollars and enabled it to distribute the various refined products needed for war-time activity with a minimum of power and steel, because it has resulted in a general improvement of through-put and efficiency.

The use of internal inhibitors was initiated for two reasons: first, because of losses due to line fouling, which reduced capacity and increased power consumption; second, because corrosion products carried by the stream were abrasive in close clearance equipment. This resulted in pump and packing failures. These problems were discussed in detail in the 1943 API Symposium on Combating Internal Corrosion of Products Pipelines.<sup>1</sup>

Of the thirteen lines reporting at that time, six were using inhibitors, two had experienced no difficulties and five had developed extensive scraper programs. Twenty companies were contacted in the present survey, and of the nineteen reporting, thirteen use inhibitors, three are contemplating using an inhibitor, one dehydrates the products, one experiences no corrosion difficulties in any of its equipment or lines and one did not indicate its position. One company uses an inhibitor in one of its lines and depends on an extensive scraping program in others. A copy of the questionnaire is shown in Appendix 1A and data are tabulated in Appendix 1B.

As emphasized in the 1943 Symposium on Products Pipelines, internal corrosion is associated with water and with oxygen. In this connection it can be considered in the light of atmospheric corrosion where experimental investigations<sup>2</sup> indicate that the primary cause is the actual dissolving of iron in water, which takes place before any other chemi-

\*A paper presented to Subcommittee on Internal Corrosion of Products Pipelines of the Division of Transportation, before the Twenty-Sixth Annual Meeting of the American Petroleum Institute, Chicago, Illinois, November 11, 1946.

\*Editor of NACE journal, Corrosion.



cal action starts. A film of liquid water adhering to the metal is necessary.

Oxygen acts as an accelerator by reacting with ferrous hydroxide and removing hydrogen. The pipe metal has the same tendency to adsorb moisture from the products as it would have to adsorb moisture from the atmosphere, and although the gasoline does not have the same concentration of oxygen as found in the atmosphere, it still furnishes a continuous supply. In addition to the tendency of the metal to absorb a water film, the lighter products<sup>3</sup> permit a preferential wetting of the steel by water. The problem, then, is one of eliminating the water, the oxygen, or of inhibiting the reaction.

Briefly the mechanism of inhibition involves building an impermeable membrane between the metal and the atmosphere, or in this case the product containing dissolved oxygen. It has been shown that clean steel has an invisible iron oxide<sup>4</sup> film, and that rust appears because the film is continually being broken and new permeable iron oxide deposits are laid down. The purpose of the inhibitor is to repair these breaks with non-permeable membranes. For example, with chromates,<sup>5</sup> a mixture of hydrated ferric and chromic oxides is laid down which will not permit passage of corrosive agents. With nitrites,<sup>6</sup> the action is probably one of building a straight ferric oxide film. With mercaptobenzothiazole,<sup>7</sup> the inhibition is probably due to the adsorption of a layer of the positively charged mercaptobenzothiazole radical on the steel which screens out the attacking elements.

The selection of an inhibitor involves an initial choice between a

water soluble material, an oil soluble material, or a material that is distributed between the oil and water phase. The major portion of research in this field has been done by Phillips Petroleum Company, Atlantic Refining Company and Shell Oil Company.

The Phillips and Atlantic Refining lines being among the oldest, were the first to give trouble, and these companies were the first faced with developing internal inhibitors for products pipelines. Both of these companies carried on extensive research and development programs.

Phillips<sup>8</sup> found residual treating fluids from refining operations causing a great deal of trouble in the refinery end of their line. Their investigation, covering the period 1934-1937, led them to the following conclusions:

1. That the inhibitor should be soluble in gasoline and slightly soluble in water;
2. It should not lose its activity by reacting with any component of the gasoline;
3. It must not alter the properties of the gasoline;
4. It must possess an affinity for metals.

From a study of several hundred compounds mercaptobenzothiazole was chosen as the most effective and it was put into field application in February, 1937, by Phillips Petroleum Company.

Buffalo-Keystone Pipe Line<sup>9</sup> operated by the Atlantic Refining Company, studied the suitability of sodium chromate, a water soluble inhibitor. Their program consisted of laboratory beaker tests, ½-inch pilot pipeline, and field test spools in addition to rather exhaustive testing

of effect of chromate on the various refined petroleum products. The Buffalo-Keystone system initiated their field program in April, 1935. Most companies which are using or have used chromate have done so on the basis of this work and operational experience.

Shell Oil Company experienced internal pipeline corrosion soon after they built their products lines. They carried out an extensive research program,<sup>6a</sup> which resulted in the choice of sodium nitrite as the outstanding material for application to the products pipelines. They found that the nitrite did not affect and was not affected by any of the products. Shell developed the patented field application of sodium nitrite as an internal corrosion inhibitor in products pipelines and has licensed and supplied technical advice to all of the users of sodium nitrite as a products pipeline inhibitor.

Table I shows the companies contacted, their practices in regard to using inhibitors and the date of starting the inhibitor program. All of the operators but one uses the inhibitor in all products. The initial date shown for application of inhibitors to products pipelines was April, 1935.

The replies to Section C of the questionnaire (Table III) indicate that all of the companies have determined after extensive tests that the inhibitors used do not materially affect the products pumped.

In applying inhibitors it is necessary to reconsider their function, that of repairing breaks in the iron oxide film. In general, it has been considered advisable to inject the inhibitor continuously because film breaks are inevitable. Inspection of

Table II shows that inhibitor injection is continuous in every case but one. Companies A, D, F, J, K, and T use gravity feeders to inject sodium nitrite solution. Companies E, G, O, and Q use proportioning pumps to inject sodium chromate solution. Company's I, L and P employ automatic proportioning equipment to inject the oil solution of mercaptobenzothiazole.

Some study and attention has been directed toward determining the maximum carrying distances of the various inhibitors. However, it has been found convenient and feasible to alter the amount and concentration of inhibitor solutions to accommodate varying distances between pump stations rather than establish injection points at remote regularly spaced points on the lines. The practice of withdrawing the water at pumping stations removes the unreacted water soluble inhibitors. As shown in Table IV, analyses of the water samples taken from the downstream stations are used as the criteria for the quantity of water soluble inhibitor required while coupon data and operating experience are used to determine the injection points for the oil soluble inhibitor.

There is some confusion in the answers concerning precautions, both in regard to handling the chemicals and disposition of the effluent water. (See Table V.) It should be emphasized that each of these chemicals is somewhat toxic and should be handled with special safety precautions and respect. Note Appendix II for information on chromate and nitrite. The toxic nature of the water withdrawn from the lines using these inhibitors requires that care be

exercised in the disposal of the effluent.

One factor not brought out in the questionnaire is that all users of corrosion inhibitors in products pipelines use caustic soda or sodium carbonate to adjust the effluent water drawn off downstream to a pH of seven or above. After lines have been inhibited for a number of years, some of the operators find that the amount of alkaline material required is greatly reduced.

All lines using inhibitors and/or scrapers have provisions for removing water and scale through hay tanks, sediment tanks, sediment traps, or settling tanks.

Under the heading "Use of Mechanical Aids" (Table VI), we have a variety of opinions. With the exception of Companies G, O, and I, the scraper runs are considered effective from 40 to 100 miles. The condition of the line and design of the scraper undoubtedly have considerable bearing on length of effective scraper runs. Examination of Table VI shows that where inhibitors are used, the general opinion in the industry is that the primary purpose of the scraper is to remove water and sediment.

It is well to point out that almost every company, regardless of inhibitor being used, has found it advisable when initiating the inhibitor program to use heavy doses of chemical and to carry out an intensive scraping program. This was brought out in the 1943 symposium. Some of the reasons for this are: (1) Inhibitor has to be distributed throughout the line; (2) The old rust absorbs and consumes the inhibitor; (3) As the corrosion activity is stifled the tubercles and rust lose the bonding

effect accruing from corrosion activity and tend to slough off. The scraper program hastens the removal of this material and at the same time may help spread the inhibitor. A point not brought out in the questionnaire is that after lines have been cleaned up, some operators<sup>10</sup> find it unnecessary to run scrapers.

Inspection of Table VII shows that all of the pipeline operators who have an established inhibitor program report good internal pipe conditions. Several operators who have recently started programs have not had time to accumulate significant data. Six of these lines had scraper programs prior to starting their inhibitor programs. Two companies, C and E, (except one line) state that with regular scraping programs they have been able to maintain a good "C" factor, but they do not give any data on the condition of their line. H company has not experienced any corrosion difficulties and states that the pipe is in excellent condition. Although no data was collected on the quantity of scale removed from the various lines, it is most probable that under corrosive conditions those lines using scrapers alone are suffering a greater metal loss than those using inhibitors. The cost per barrel mile figures were not tabulated because the data received was not comparable.

The inhibitors practices and "C" factors as expressed by the modified Hazen and Williams formula are summarized in Table VIII. Three companies use mercaptobenzothiazole in a total of 2103 miles of pipe. Four companies use sodium chromate in 2377.5 miles and six use sodium nitrite in 4891 miles of pipe.

One company is preparing to use nitrite.

The average "C" factors before the inhibitor program was started ranged from 90 to 142, and they have been increased to from 130 to 161. It was brought out in the 1943 symposium that an increase of ten points in "C" factor represents about seven percent<sup>11</sup> increase in throughput without increase in power. Using

this criteria, it can be safely stated that an improvement of ten to fifteen percent has been achieved.

### Acknowledgment

The author is indebted to the nineteen companies contacted for answering the questionnaire very promptly and for supplying the data presented in this paper. This courtesy is greatly appreciated.

### References

1. API Proceedings, IV. Production, 39-135 (1943).
2. J. F. G. Hicks, Physico-Chemical Causes of Corrosion, *J. Ph. Chem.*, **33**, 780 (1929).
3. J. M. Pearson, Combating Internal Corrosion, API Proceedings, IV. Production, 67 (1943).
4. U. R. Evans, Metallic Corrosion, Passivity & Protection, Longmans Green & Co., N. Y., 1946, p. 1.
5. T. P. Hoar and U. R. Evans, The Passivity of Metals, Part VII. The Specific Function of Chromates. *J. Chem. Soc.*, **1932**, 2476.
6. A. Wachter & S. S. Smith, Preventing Internal Corrosion of Pipe Lines, *Ind. & Eng. Chem.*, **35**, 358-67 (1943) Mar.
- 6a. A. V. Solov'ev, Electrochemical Investigation of the Anti-Corrosive Properties of Sodium Nitrite, *Compt. Rend. Acad. Sci. URSS*, **14**, 295-8 (1937) Feb. (in English).
7. Charles A. Mann, Organic Inhibitors of Corrosion, *Trans-Electrochem. Soc.*, **69**, 115-129 (1936).
8. L. C. Morris and W. A. Schulze, Internal Corrosion of Gasoline Pipe Lines, *Oil & Gas J.*, **38**, 205 (1939) Nov. 17.
9. H. G. Schad, Symposium on Combating Internal Corrosion of Products Pipe Lines, API Proceedings, IV, Production, 44 (1943).
10. S. S. Smith and R. K. Schulze, Internal Corrosion of Products Pipe Lines, API Proceedings, IV. Production, 99 (1943).
11. API Proceedings, IV. Production, 57 and 102 (1943).

### APPENDIX 1A

Questionnaire which was mailed September 16, 1946, to twenty companies operating products pipelines.

#### *Use of Corrosion Inhibitors In Products Pipelines*

This questionnaire is an attempt to secure comparable information concerning the practices of the various pipelines in the use of internal inhibitors in products pipelines. This information is to be used for paper for November meeting of American Petroleum Institute.

If you use more than one inhibitor or have widely different conditions, please discuss each one.

#### A. General

1. What products do you pump?
2. Do you use corrosion inhibitors?
3. If above is yes, do you use it in all products?
4. What inhibitor do you use?
5. What was the basis of your choice?
6. What development work did you do before choosing an inhibitor? Laboratory? Field?
7. What was date of initial field application?

### B. Injection

1. Do you inject the inhibitor continuously? If discontinuous, what is basis and how frequent is it used?
2. What type of injecting equipment do you use? (Gravity feeder, manual proportioner, automatic proportioner?)
3. What solvent do you use?
4. What strength of solution do you use?
5. How often do you recharge the injector?
6. What special equipment or precautions are necessary in handling inhibitor?
7. What is the determining factor in location of injector points? Is it carrying distance or location of stations?

### C. Effect of Inhibitor on Product

1. Has the use of inhibitors adversely affected the specification properties of any products? Please discuss in some detail.
2. Has the presence or absence of corrosion inhibitors affected the gum inhibitors in any of the products?
3. Have you experienced any emulsion difficulties which might be attributed to application of inhibitor program?
4. Please indicate any other interesting results as regards changes in chemical or physical properties which you have experienced.

### D. Control

1. On what basis do you determine the amount of inhibitor injected?
2. What is your routine for sampling and testing?
3. What chemical analyses do you run?

### E. Removal and Disposal of Water

1. How do you remove water from the line? Separator tanks? Sediment traps? Filters?
2. Is it necessary to reinject inhibitor at point of water withdrawal?
3. Are special precautions necessary in disposing of waste?
4. How do you dispose of effluent containing inhibitor to avoid pollution of streams, ground water supplies, etc?
5. How is the disposal controlled?

### F. Use of Mechanical Aids

It is the opinion of some pipeline men that scrapers are effective for only very short distances beyond the point of introduction.

1. How effective have scrapers proven in your system and what is the effective distance in a single run?
2. What is the primary function of your scrapers?
3. Is your product cloudy during a scraper run? In your opinion, is this sediment and debris material that has been scraped loose from the wall by the scraper alone or has this material been previously loosened or removed by inhibitor and just brought in by the scraper?
4. In what products do you run scrapers?

### G. Results of Inhibitor Program

1. Was line designed as product system or converted from crude?
2. How long was line in product service before starting inhibitor program?
3. What program was carried out before inhibitor injection was started?
4. How long has your inhibitor program been in operation?
5. How many miles of pipe are treated?
6. Can you give a definite statement or opinion as to the general condition of the internal surface of the pipe?
7. It is a general practice to evaluate the condition of the line on the basis of the C Factor in the Hazen Williams Formula. Using this as a criterion,
  - a. What was your rating at the start? Your average rating now? Your peak rating? Your minimum rating?
  - b. To what factors do you attribute these variations?
8. What is the cost of the inhibitor program per barrel mile?
9. Any charts, data or information not covered above which is pertinent to this study will be appreciated.

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## APPENDIX IB

Tabulation of data received in answer to the questionnaire is recorded in the tables reproduced on the following pages.



TABLE I  
GENERAL

Company	Products	Inhibitor Program			
		Use?	What?	All Products	Initial Date
A	Gasol., Kero., No. 2 Fuel Oil	Yes	Sodium Nitrite	Yes	March, 1943
B	No report received	—	—	—	—
C	Gasol., Kero.	No	None	—	—
D	Gasol., Furn. Oil	Yes	Sodium Nitrite	Yes	April, 1942
E	Gasol., Fuel Oil	No	None	—	—
	Condensate	Yes	Sodium Chromate	Yes	Jan., 1945
F	Gasol., including Aviation	Yes	Sodium Nitrite	Yes	Near future
G	Gasol., Kero., Furn. Oils, Diesel Oils	Yes	Sodium Chromate	Yes	April, 1935
H	Butane, Gasol., Kero., Fuel Oil	No	None	—	—
I	Butane, unleaded Motor Fuel components, Aviation Gasol., Kero. & Distillates	Yes	Mercaptobenzo-thiazole	*No	Feb., 1937
J	Gasol., Kero., refined Fuel Oils	Yes	Sodium Nitrite	Yes	Sept., 1942
K	Propane to Fuel Oil	Yes	Sodium Nitrite	Yes	1939
L	Gasol., Kero., Fuel Oils	Yes	**Mercaptobenzo-thiazole	Yes	1943
M	No data given	No	None	—	—
N	Products	No	—	—	—
O	Gasol., Kero., ref. Fuel Oils	Yes	Sodium Chromate	Yes	Sept., 1946
P	Gasol., Kero.	Yes	Mercaptobenzo-thiazole	Yes	1940
	Gasol., Kero.	Yes	Spec. Product	Yes	1941
Q	Aviation Gasol., Gasol., Kero., Navy Diesel	Yes	Sodium Chromate	Yes	Aug., 1944
R	No data given	No	None	—	—
S	Butane & Gasol.	No	None	—	—
T	Gasol. & Kero.	Yes	Sodium Nitrite	Yes	Jan., 1945

\*Not required with butane, kerosene, distillate or 100 octane aviation gasoline.

\*\*Other development in progress.

TABLE II  
INJECTION

Company	Inhibitor	Continuous or		Equipment	Solvent	Strength	Recharge	Precautions	Location of Injector
		Intermittent							
A	NaNO <sub>2</sub>	Con.	Grav feed.	Water	Varied	As required	Locked storage space for chem. in stock; rubber gloves & goggles	Convenient to station location	
D	NaNO <sub>2</sub>	Con.	Grav feed.	Water	2—20%	Daily	None	Location of stations	
E	Na <sub>2</sub> CrO <sub>4</sub>	Con.	Press. diff. pump on suet.	Water	Approx. 10%	Daily	None	Beginning only	
F	NaNO <sub>2</sub>	Con.	Grav. feed.	Water	—	Daily	No data given	—	
G	Na <sub>2</sub> CrO <sub>4</sub>	Con.	Prop. pump	Water	—	—	None	Carrying dist. is criterion but coincides with pump sta. location	
I	MBT	Int.	Auto Prop.	Light Oil	1 1/4 lb./pt. oil per 1000 bbls.	Dependent on rate	None	Dependent on carrying distance & location of stations	
J	NaNO <sub>2</sub>	Con.	Grav. feed.	Water	—	Daily	Rubber gloves, goggles, rubber apron	Location of stations	
K	NaNO <sub>2</sub>	Con.	Grav. feed.	Water	Various	Daily	Normal precautions in handling product of mild toxicity	Both	
L	MBT	Con.	Auto. prop.	Fuel oil	Variable	Bi-weekly	None	Location of stations	
O	Na <sub>2</sub> CrO <sub>4</sub>	Con.	Auto. prop.	Water	Experimenting	As required	Gloves & masks for mixing	Location of stations	
P	MBT	Con.	Pressure lubricator	Lube oil	1 lb./1 gal.	Daily	None	Location of stations	
	Spec. Prod.	Con.	Pressure lubricator	Water	1 oz./3 gal.	Daily	None	Location of stations	
Q	Na <sub>2</sub> CrO <sub>4</sub>	Con.	Motor driven plunger pump from tank	Water	—	As required	Gloves, goggles, aprons, etc., for mixing	Both	
T	NaNO <sub>2</sub>	Con.	Grav. feed.	Water	Varied	Daily	Gloves, goggles, apron and eye shield	Location of stations	



**TABLE III**  
**EFFECT OF INHIBITOR ON PRODUCT**

<u>Company</u>	<u>Inhibitor</u>	<u>Specification Properties</u>	<u>Gum Inhibitors</u>	<u>Emulsion Difficulties</u>	<u>Any Other Changes in Properties</u>
A	NaNO <sub>2</sub>	None	None	None	None
D	NaNO <sub>2</sub>	None	None	None	None
E	Na <sub>2</sub> CrO <sub>4</sub>	None	—	None	—
F	NaNO <sub>2</sub>	Just starting	—	—	—
G	Na <sub>2</sub> CrO <sub>4</sub>	None	None	None	None
I	MBT	*None	None	None	None
J	NaNO <sub>2</sub>	None	None	None	None
K	NaNO <sub>2</sub>	None	None	None	None
L	MBT	Appears to have slight effect on some oxid. inhibitors	Not conclusive	None	—
O	Na <sub>2</sub> CrO <sub>4</sub>	None noted	Not conclusive	None	None
P	MBT	None noted	No	No	None
	Spec. Prod.	None noted	No	No	None
Q	Na <sub>2</sub> CrO <sub>4</sub>	None	None	None	None
T	NaNO <sub>2</sub>	None	None	None	None

\*Numerous field tests have not shown any change in color, gum content, A. S. T. M. distillation, or octane ratings.

**TABLE IV**

**CONTROL**

<u>Company</u>	<u>Inhibitor</u>	<u>Basis</u>	<u>Sampling &amp; Testing</u>	<u>Chemical Analyses</u>
A	NaNO <sub>2</sub>	Conc. in effluent water	Two-week composite	Nitrite & pH
D	NaNO <sub>2</sub>	Conc. in effluent water	Samples tested at two-week intervals	Nitrite & pH
E	Na <sub>2</sub> CrO <sub>4</sub>	Conc. in effluent water	Weekly	Chromate & pH
F	NaNO <sub>2</sub>	Not started yet	—	—
G	Na <sub>2</sub> CrO <sub>4</sub>	Conc. in effluent water	Samp. effluent water	Chromate
I	MBT	Test coupons & operating records	At irregular intervals	pH
J	NaNO <sub>2</sub>	2% nitrite in effluent water	Anal. of 15-day comp. from hay tanks	Nitrite & pH
K	NaNO <sub>2</sub>	Anal. of effluent water	—	—
L	MBT	Line efficiency	Test strips	None
N	—	In development stage	—	—
O	Na <sub>2</sub> CrO <sub>4</sub>	Conc. in effluent water	Daily samples anal. in present initial period	Chromate
P	MBT	Test sections	Test sections	None
	Spec. Prod.	Test sections	Test sections	None
Q	Na <sub>2</sub> CrO <sub>4</sub>	Conc. in effluent water	Spot checking	Chromate
T	NaNO <sub>2</sub>	Conc. in effluent water	Anal. of 15-day comp. from hay tanks	Nitrite & pH

TABLE V  
REMOVAL & DISPOSAL OF EFFLUENT WATER

Company	Inhibitor	Provisions for Removal	Reinject Inhibitor	Special Precautions	Method of Disposal
A	NaNO <sub>2</sub>	Filters & traps	Usually	Yes	By dilution & thru sanitary sewage system
C	None	Sediment tanks	None	No	—
D	NaNO <sub>2</sub>	Hay tanks	No	Yes	Leaching pit
E	None	Sediment tanks	None	No	—
	Na <sub>2</sub> CrO <sub>4</sub>	Sediment trap	No	None	—
F	NaNO <sub>2</sub>	Not started yet	—	—	—
G	Na <sub>2</sub> CrO <sub>4</sub>	Separation traps	No	None	No problem
H	None	Sediment traps & separation tanks	—	No	—
I	MBT	Sediment traps	No	None	—
J	NaNO <sub>2</sub>	Hay tanks	No	Yes	Diluted to 0.01%
K	NaNO <sub>2</sub>	Settles in tanks	No data given	Yes	Diluted to mild concentration
L	MBT	Separator tanks	No	No	Station drainage
N	None	Settling tanks	No	No	—
O	Na <sub>2</sub> CrO <sub>4</sub>	Separator tanks	Yes	Yes	Bury in disposal pits
P	MBT	Settles in tanks	Yes	No	Drain tank bottoms
	Spec. Prod.	Settles in tanks	Yes	No	Drain tank bottoms
Q	Na <sub>2</sub> CrO <sub>4</sub>	Traps	No	No	No problem
T	NaNO <sub>2</sub>	Filters	Yes	Yes	Dilution

TABLE VI  
USE OF MECHANICAL AIDS

Company	Inhibitor	Effectiveness	Function	Cloudy	When
A	NaNO <sub>2</sub>	50 miles	Water removal	Yes	H. B. Gaso.
C	None	No data given	Remove water & scale	—	—
D	NaNO <sub>2</sub>	Quite good	Clean line & remove water	No	All
E	None	100 miles	Water & scale removal	Yes	All
	Na <sub>2</sub> CrO <sub>4</sub>	100 miles	Wiping or swabing out	Slight	All
G	Na <sub>2</sub> CrO <sub>4</sub>	200 miles	Remove water	Turbid	Heavier products
H	None	Depend on scrapers & traps	Remove mill scale	Slight	—
I	MBT	60 miles	Water removal	No	Motor fuel, ref. base stock
J	NaNO <sub>2</sub>	Depend on roughness & design	Remove water	Yes	Gaso.
K	NaNO <sub>2</sub>	Up to 125 miles	Remove water	Both	—
L	MBT	80 miles	Remove water	No	Normally fuel oil
N	None	—	Remove sediment & water	—	—
O	Na <sub>2</sub> CrO <sub>4</sub>	114 miles	Distribute inhibitor	Yes	Gaso.
P	MBT	No scraper	—	—	—
	Spec. Prod.	50 miles	Remove water & scale	Yes	All
Q	Na <sub>2</sub> CrO <sub>4</sub>	150 miles	Remove water & sediment	Yes	—
T	NaNO <sub>2</sub>	40 miles	Remove debris	Yes	—

**TABLE VII**  
**RESULTS OF INHIBITOR PROGRAM**

Company	Design	Previous Program		Inhibitor	Period of Application	Miles	Condition	Start	C Factor (Modified H & W Formula)		
		Years	Treat.						Av.	Max.	Min.
A	Products but old pipe	None	None	NaNO <sub>2</sub>	3-1/2 yrs.	265	Clean & free of corrosion	Old pipe not sig.	155	—	—
C	Products	12	Scrapers at 10-day intervals	None	None	No data given	No data given	No data given	145-150	—	—
D	Products	5	None	NaNO <sub>2</sub>	*10 yrs.	2000	Good	130	150	155	140
E	Products	No data given	None	None	None	No data given	No data given	—	145-150	—	—
F	Products	4	Scrapers	Na <sub>2</sub> CrO <sub>4</sub>	21 mos.	37-1/2	Smooth	128	142	145	141
F	Products	Just starting	—	NaNO <sub>2</sub>	—	—	— pipe	—	—	—	—
G	Products	3-1/2	Scrapers	Na <sub>2</sub> CrO <sub>4</sub>	11 yrs.	815	Excellent	120-125	155-160	165	150
H	Products	No data given	—	None	None	647	Good as new	—	155	—	—
I	Products	6	Scrapers in slug of water yearly	MBT	6 mos. to 9 yrs.	1053	Excellent	100	138	140	136
J	Products	3/4	None	NaNO <sub>2</sub>	4 yrs.	1261	Slight rusting	142	**161	162	159
K	Largely products	1-1/2	Scrapers	NaNO <sub>2</sub>	6 yrs.	900	Clean grey	125	155-160	160	—
L	Products	1	Scrapers	MBT	3 yrs.	700	Inadequate inspection	—	No data given	—	—
O	Products	15	Scrapers 10 yrs.	Na <sub>2</sub> CrO <sub>4</sub>	2 Mos.	50	Covered with iron oxide	90	130	140	110
P	Products	1/8	—	MBT	6 yrs.	350	Excellent	—	149-152	—	—
P	Crude	8	Scrapers	Spec. Prod.	5 yrs.	—	Inadequate inspection	92	132	—	—
Q	Products	1/8	None	Na <sub>2</sub> CrO <sub>4</sub>	14 Mos.	1475	Corrosion stopped	140	—	150+	—
T	Products	3	None	NaNO <sub>2</sub>	18 Mos.	465	Very much improved	130	150	158	147

\*1936—1941 sodium sulfite was used. 1942—date sodium nitrite has been used.

\*\*Data on main line only.

**TABLE VIII**  
**SUMMARY**

Company	Products	Inhibitor	Miles	Duration of Program	C Factor (Modified H & W Formula)	
					Start	Av.
L	Gas., Kero., & Fuel Oils	Mercaptoben-zothiazole	700	3 yrs.	No data given	
I	Butane, Gas., Kero., & Distillates	Mercaptoben-zothiazole	1,053	6 mos.-9 yrs.	100	138
P	Gas., Kero.	Mercaptoben-zothiazole	350	6 yrs.	—	149-152
		Spec. Product	—	5 yrs.	92	132
O	Gas., Kero., & Fuel Oil	Sodium Chromate	50	2 mos.	90	130
Q	100 Oct. Aviation, thru Fuel Oils	Sodium Chromate	1,475	14 mos.	140	—
E	Condensate	Sodium Chromate	37.5	21 mos.	128	142
G	Gas., Kero., Furn. Oils, D. Fuel	Sodium Chromate	815	11 yrs.	120-125	155-160
F	H. B., Prem., 91 & 100 Octane Gas.	Sodium Nitrite	No data given	Program just starting	—	—
T	Gas., & Kero.	Sodium Nitrite	465	1-1/2 yrs.	130	150
A	Gas., Kero., No. 2 Fuel Oil	Sodium Nitrite	265	3-1/2 yrs.	Old pipe not sig.	155
J	Gas., Kero., Fuel Oils	Sodium Nitrite	1,261	4 yrs.	142	*161
D	Gas., Furn. Oil	**Sodium Nitrite	2,000	10 yrs.	130	150
K	Propane to Fuel Oil	Sodium Nitrite	900	7 yrs.	125	155-160

\*Data on main line only.

\*\*1936—1941 Sodium sulphite and 1942 to date sodium nitrite.

## APPENDIX II

**Toxicity of Sodium Chromate\***

Trivalent and lower chromium compounds are not particularly toxic. The action of the higher valent compounds (sodium chromate and dichromate) is generally as follows and seems to be due to the oxidizing power of these compounds.

**INHALATION**—When dusts or solutions of chromium compounds are inhaled, irritation occurs which is marked in early stages by nose bleed followed by more painful and deep irritation which later develops into perforation of the nasal septum.

**INGESTION**—When swallowed, the chromium compounds cause a disagreeable taste, sore throat, vomiting, pain, diarrhea, unconsciousness, dilated pupils, very slow respiration and muscular cramps. In addition to producing severe gastric upset, nervous symptoms such as headache, stiffness at the back of the neck and cramps. The blood pressure is abnormally lowered. Chromium compounds corrode and destroy kidney tissues and death occurs within 1-48 hours. Less than 0.5 grams of potassium dichromate may cause severe poisoning; the lethal dose is below 8 grams (about 1/3 ounce), 6 grams of chromic acid may be fatal.

**SKIN CONTACT** — Chromium compounds cause ulcerous dermatitis which eventually develops into "chrome holes." These ulcers are slow in forming and are deep and painful. The skin may be entirely removed and the tissues show scars when the scab is sloughed. Chrome ulcers should be treated immediately as they continue for long

periods and may spread, however, healing is usually complete when the individual is removed from chromium containing atmospheres, or when the base is cleared. The base of the fingernails is especially susceptible to chrome ulcers, as well as the feet if the shoes are soaked with chromium compounds.

**FIRST AID**—For ingestion, the stomach should be washed and vomiting induced if it is not present; call the doctor immediately. For skin contact, wash thoroughly with a solution of 5 percent sodium thiosulfate, and apply an antiseptic healing cream of the lanolin-phenol type. The nasal passages may be protected by frequently applying during the course of the working day, pledgets soaked in mineral oil or liquid petrolatum. A heavy grease consisting of zinc ointment and Peru Balsam may be used in the nasal area before entering contaminated atmospheres. However, for more adequate protection, a chemical respirator should be used.

**Toxicity of Sodium Nitrite†**

**SODIUM NITRITE** — Dust or vapor inhalation or swallowing produces a fall in blood pressure due to the nitrite action, however, it is apt also to cause a digestive upset. Symptoms consist of headache, increased respiration rate, and perhaps an increase of surface temperature of the body. Excessive amounts cause cyanosis (blue color), asphyxia and even death.

\*Data compiled by Benson and Associates, Private Communication.

†A Manual of Pharmacology by Sollman Saunders, Philadelphia, 1943.

## Cathodic Protection Rectifiers\*

*By W. L. Roush and E. I. Wood*

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**C**ORROSION OF METALS subject to moisture is analogous to the destructive power of the atomic bomb to ships at sea. Whereas the atomic bomb destroys all material in a limited space, corrosion is world wide. Prevention of corrosion was pioneered by the men who are our corrosion engineers of today. Cathodic protection equipment was developed through the combined efforts of corrosion engineers and manufacturers of electrical equipment.

Cathodic protection equipment may be divided into several groups: Wind chargers; engine generator sets, and rectifiers of various types such as air-cooled, fan-cooled, and oil-immersed.

### Wind Chargers and Engine Generator Sets

Wind chargers are used primarily in isolated places inaccessible to electric power or natural gas. As their name implies, wind charges depend upon the wind for power, and cathodic protection can only be obtained when the wind is blowing. This equipment has moving parts

which require maintenance. A few late model wind chargers employ a storage device to insure current and voltage during lulls in the wind.

Engine generator sets are used in applications where electric power is not available. These engines burn natural gas, gasoline or kerosene, with natural gas taken from the protected gas line being the ideal set-up. These engines also have moving parts which require maintenance and periodic checks.

### Rectifiers

Rectifiers, the most widely used of these cathodic protection units, are rapidly replacing the engine generator sets and wind chargers where rural electric power is available. Since rectifiers, with the exception of large fan-cooled units, do not have moving parts, little maintenance is required for the life of the rectifier stacks. Rural electrification is making electric power more and more available for protection of pipelines that previously used gas engines, wind chargers or were unprotected.

The life of the rectifier depends on several important factors: type of unit, humidity, prevailing tem-

\*A paper presented at the Annual Meeting of NACE at Kansas City, Mo., May 7-9, 1946.

perature, corrosive atmospheres, as the following table shows:

	Fan Cooled	Self Cooled	Oil Immersed
High humidity	Fair	Good	Excellent
Low humidity	Good	Excellent	Excellent
Moving parts	Yes (fan)	No	No
Corrosive Atmosphere	No	Good	Excellent

These factors are more or less dependent upon each other and should be considered before a choice of the type of rectifier unit is made.

Air-cooled rectifiers can be used in high or low humidity, with a limited amount of corrosive atmosphere. In a corrosive atmosphere with high humidity, the life of the rectifier is very materially affected by the type of varnish used on the rectifier stacks. The varnish should be capable of withstanding the corrosive gases found in refineries.

Alternating current supply phases should be considered in making a selection of any of the different types of rectifiers. The overall efficiency of the three-phase rectifier unit is approximately 15 to 20 percent higher than a single-phase unit. Based on the above fact, three-phase power should be used when available. The economies of three-phase and single phase power requires consideration when a new power line is to be installed.

### Air-Cooled Rectifiers

The air-cooled rectifier unit consists of an outdoor, semi-bulletproof sheet-metal house in which are located multi-tap transformer, rectifier stacks, voltmeter, ammeter, primary breaker and connections for line and load leads. The house is constructed of approximately  $\frac{1}{8}$ -inch thick sheet steel, with openings at the bottom and around the overhanging top to give a chimney effect

for cooling of the rectifier stacks. Small-mesh screening is placed horizontally in the bottom and vertically at the top. The vertical screen on the removable top eliminates any possibility of bird nests, with the mesh of the screen prohibiting the building of nests by dirt daubers and yellow jackets on the rectifier plates. These nests on the rectifier stacks are an aid to the rectifier enemies, corrosive and wet atmospheres.

The house has a hinged door, with provision for using a hasp lock; and has brackets and hanger irons for pole mounting.

Fuses are provided for each rectifier stack, and in the event one stack shorts, the fuses blow and clear the shorted stack from the circuit. The rectifier will continue to operate on reduced current. Fuses are mounted on a hinged micarta panel.

### Fan-Cooled Rectifiers

The fan-cooled rectifier unit consists of outdoor sheet-metal house in which are located a line-starter with overload heaters, multi-tap transformer, rectifier stacks, voltmeter, ammeter, a small breaker for starting the fan and closing the line-starter, and connections for line and load leads. The house is constructed of approximately  $\frac{1}{8}$ -inch thick, semi-bulletproof sheet steel, with no openings at the top. The fan draws air in at the bottom and the sides and forces the stream over the rectifier stacks, and out the screened top. The house has a hinged door with provisions for locking, and has brackets and hanger irons for pole mounting.

Fuses are provided for the same purpose as stated in the discussion of the self-cooled rectifier, and are

mounted on a hinged micarta panel.

The oil-immersed rectifier first manufactured some ten years ago, had a multi-tap transformer, and disc-type rectifier stacks. The rectifier stacks were placed inside a "diving bell," which was immersed in oil. The purpose of the diving bell was to provide an air chamber around the rectifier stacks. This type oil-immersed rectifier was limited to very low wattages.

The second type oil-immersed rectifier used the diving bell principle, and in addition used a fan to agitate the air. This type unit was an improvement, with increased wattages possible.

A newer rectifier stack was developed, and known as the "plate type." Experiments showed that the plate-type rectifier could be immersed in direct contact with the oil. The oil-immersed rectifier was growing up.

After considerable research, the proper relation was found between physical size, amount of oil, and direct current wattage. With technical data complete, the oil-immersed tank was redesigned.

First consideration was given to units with direct current wattage less than 900 watts. These units were to be designed for pole mounting. An angle-iron frame was to be used to mount the transformer and rectifier stacks, with a micarta panel mounted on top of the frame with provisions for tap-changer, fuses, and primary a.c. and secondary d.c. connections. With the panel on top, the voltage taps could be varied without removing the frame. The individual stacks were fused, in order to isolate any stack that became shorted. Field tests showed that fusing of the

stacks was unnecessary, which resulted in elimination of the fuses.

The tank was to be designed similar to the distribution transformer, with an overhang and nipple on each side for conduit connections for both a.c. power and d.c. load leads.

The instruments, voltmeter and ammeter, were mounted in a weatherproof box, with a glass panel in the cover to facilitate reading of the instruments. This type instrument box became obsolete when the instruments were housed in separate sealed housings which were mounted on the tank. These housings have a glass front to enable reading of the instruments from outside of the tank.

There are two types of mountings for the rectifiers: pole-mounting and platform-mounting. Pole-mounted rectifiers are provided with hanger irons to hang on cross-arms. The brackets, to which the hanger irons are bolted, can be used to mount the rectifier on the leg of a water tank, or other places not suitable for cross-arm mounting.

The oil-immersed rectifier is the latest development, and is the type best suited for either damp or dry corrosive atmospheres. The transformer, rectifier stack, tap-changers, and connections are under oil. There is no circulation of air inside the tank with gasketed lid.

Anti-siphon leads, both primary a.c. and secondary d.c., are brought out through sealed fittings. A primary breaker is connected to the a.c. fitting, and this breaker is used to start and stop the rectifier. The a.c. outlet is usually one-inch pipe threads, or one-inch knockout, and the d.c. outlet is usually two-inch pipe threads.



The platform mounting is suitable for mounting on a concrete pad or timbers. In areas subject to floods, the rectifier may be mounted on timbers of suitable height.

Over 400 oil-immersed rectifiers have been placed in service with d.c. loads ranging from 70 to 4500 watts. Some of these oil-immersed cathodic protection rectifiers have been in service for six years. These rectifiers

have been installed in all parts of the United States, and in several foreign countries requiring continuous operation under all kinds of atmospheric conditions, with temperatures ranging from below zero to 120° Fahrenheit. With no plate failures reported to date, experience shows that the oil-immersed rectifier is the most adaptable for all kinds of atmospheric conditions.



## Fundamental Factors in Corrosion Control\*

By Dr. Herbert H. Uhlig

Associate Professor of Metallurgy, Massachusetts Institute of Technology, Cambridge, Massachusetts

THE subject of corrosion increasingly impresses one with its international scope and importance. There are several reasons for this beyond the fact that corrosion problems, whether recognized or not, affect all consumers of metals, and therefore enter as an economic factor in the affairs of the community, and particularly its industries. One reason arises from the situation that chemical industry today operates under conditions of higher pressures and temperatures markedly more corrosive to common metal equipment than prevailed several years ago.

Whether a chemical process is practical or impractical is intimately related to rates of corrosion in the process. The power equipment industry likewise is faced with current and impending corrosion problems in the use of higher pressure steam, and with the hot gases employed in the gas turbine.

Another reason derives from conditions inspired by the recent war. The armed services were impressed in no uncertain manner that the simple difference between good equipment functioning perfectly here, and not at all in the tropics, can be a difference in the corrosion rates at

the two locations. The sailing of a warship can be and has been delayed by the corrosion failure of a small but vital valve in the maze of pipes that service the ship. Corrosion control in these instances can all too readily parallel the proverbial horseshoe nail, that "because of its want, the battle is lost."

The war in addition, as all of us know, made great inroads into our reserves of ores. The days ahead to which we may look for ready quantities of common domestic metals on a familiar price scale are indeed numbered. With our metals dwindling in availability and quantity, there is urgent need now for their conservation.

Never before have we so much felt the necessity for extended application of corrosion knowledge. This application to be fully realized must be supplemented by a program of basic research aimed to increase our understanding of the subject. Only through fundamental research can we hope to clear the path for chemical process and power development employing the higher pressures and temperatures that open up new territories and economies.

Only through further research can we have some degree of assurance that metal equipment, wherever located, or whatever the application, will have a predictable useful life, and that we are availing ourselves of

\*A paper presented at Modern Metal Protection Symposium, Cleveland, Ohio, September 21, 1946. Reprinted from Chem. & Eng. News 24, 3154-3158 (1946) Dec. 10.

every possible means to avoid sudden or premature failure. We must learn through the established methods of research how to extend useful life of metal equipment, and consequently conserve the metals we can ill-afford to squander.

All the common metals tend to revert to their ores or to compounds of lower free energy. This tendency is marked in some metals more than in others, but since the time to failure of metal structures, or the amount of metal ion contaminating the environment is our main concern, emphasis in the field of corrosion is on

rate of metal attack, rather than tendency.

The corrosion rate of a metal is controlled in several different ways. In brief, these involve application of (1) cathodic protection, (2) metallic coatings, (3) inorganic and organic coatings, (4) absorbed and reaction product films i.e. passivators and inhibitors, (5) alteration of the environment, e.g. oxygen removal, (6) metal purification, (7) alloying.

### Cathodic Protection

Cathodic protection is the one method known for preventing corrosion or for reducing the corrosion rate virtually to zero. This method is widely used to protect many miles of buried iron pipe, and is now receiving greater attention in the protection of hot and cold water tanks. A buried pipeline or water tank so protected has unlimited life. The principle of its application, in simple terms, involves neutralization of electric currents that account for the observed corrosion, and that operate between the multitudinous anodes and cathodes of the metal surface. The protection is accomplished using an external anode and connecting it to the positive terminal of a rectifier or other source of d.c. current, and the structure to be protected to the negative terminal.

Figure 1 is a sketch of a metal immersed in an electrolyte showing positive current leaving an anode area of the surface and entering the cathode areas, represented, for example, by mill scale on iron. These local action currents account for solution of the metal at the anode.

In Figure 2 the switch is closed, providing current from an external source that enters the metal oppo-

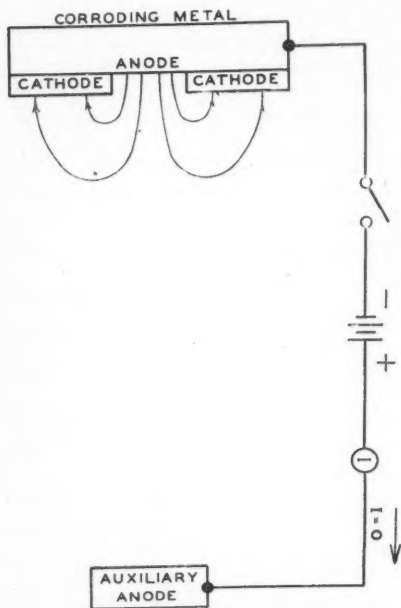


Figure 1—Sketch of a metal corroding in an electrolyte, showing local action currents. Cathodic protection current not flowing. (J. M. Pearson, "Fundamentals of Cathodic Protection," Corrosion Handbook, John Wiley & Sons, Inc.

Edited by H. H. Uhlig. In press.)

site in direction to the flow of currents from the anode, and neutralizing such currents. Corrosion, thereafter, can not occur so long as the external circuit is closed and provided external current flows adequate to overcome the local action currents.

Cathodic protection in the above manner is also accomplished using a sacrificial anode of zinc or magnesium, which sets up the necessary current protective to iron without an external power source.

The order of magnitude of required current for each square foot of iron surface ranges from 0.0002 to 0.05 ampere for flowing fresh waters, to 0.015 ampere for flowing sea water and 0.05 to 0.5 ampere for a corrosive soil. In actual applications, one or more criteria are employed to determine whether the applied current is adequate for the purpose. These include use of potential measurements, colorimetric tests for metal ions, or weight loss determinations of test pieces temporarily affixed to the protected structure.

### Metallic Coatings

The principal of cathodic protection appears in the use of zinc-coated iron, known familiarly as galvanized iron or steel. At any break in the zinc coating in contact with some aqueous solution, a current is generated by a galvanic cell made up of zinc and iron. The current flows such that iron is cathodically protected at the expense of corroding zinc, hence the term "sacrificial coating." No rusting of the iron occurs until practically all the zinc has first corroded in the neighborhood. The effective area of iron protected by the remaining zinc increases with

the conductivity of the solution causing the corrosion. In some drinking waters, iron rusts at a break in the zinc coating separated more than only one-eighth or one-fourth inch from the zinc, but in higher conductivity waters, such as sea water, the iron is continuously protected at least several inches removed from the zinc coating.

There is evidence that in hot fresh waters, the zinc coating is either less protective or reverses its polarity with respect to iron.<sup>1</sup> In accord with this observation, galvanized iron pipe used for several years in Baltimore for hot water service has been reported to corrode more by pitting than ungalvanized pipe.<sup>2</sup> In all other common service, however, so far as

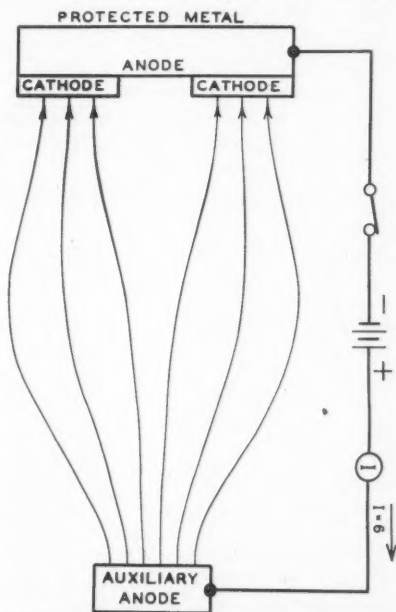


Figure 2—Sketch of a metal in an electrolyte cathodically protected using an auxiliary anode and external source of current. (J. M. Pearson.)

is known, zinc coatings are outstandingly protective.

A non-sacrificial coating, for example copper or nickel, also forms a galvanic cell with iron, but the current set up has the opposite direction to that generated by a sacrificial coating. Currents from these cells serve to increase corrosion of the base metal. Since electrolytic action can occur only at breaks in the coating, it is obvious that coatings of the non-sacrificial kind must be free of pores in order to have optimum protective value. This condition is usually approached in a coating sufficiently thick. For example, electrodeposited nickel, a coating in the order of 0.0005 to .0015 inch thick, offers good protection to iron exposed to the atmosphere.

Increasing use is made of sacrificial coatings on alloys of aluminum such as duralumin which contains about 4 percent copper. The copper alloy possesses good mechanical properties, but is subject to fairly rapid corrosion, particularly in chloride solutions. By bonding it metallurgically with pure aluminum, the rolled sheet presents a surface of pure metal of intrinsically better corrosion resistance than the underlying stronger alloy. Should a corrosion pit form in the outer coating, its progress is altered on reaching the alloy layer, such that the pit broadens rather than penetrates the sheet. This desirable behavior of duplex aluminum layers results from the fact that pure aluminum is anodic to and hence protects the copper-aluminum alloys in the same way that zinc protects iron.

Aluminum coatings on steel have appeared on the market<sup>3</sup> offering especially improved high tem-

perature oxidation resistance. Their porosity at elevated temperatures is not of great consequence because aluminum readily diffuses into areas partially coated, or the oxide soon fills the pores. Used for fresh water exposure at ordinary temperatures, however, these coatings must be especially pore free to be protective because aluminum is cathodic to iron. In sea water, however, aluminum reverses its potential in respect to iron and acts as a sacrificial coating, protecting iron galvanically at any break in the coating.

#### Galvanic Behavior Illustrated

Aluminum coatings on iron offer an illustration of galvanic behavior sensitive to environment. Another example is tin coating, this being noble to iron on the outside of our very familiar tin cans, but less noble than iron on the inside, where oxygen concentration is low. The reversal of potential is fortunate for the food processors, for otherwise tin cans would be subject to fairly rapid perforation by pitting. A pin hole in a tin coating cathodic to iron serves to concentrate considerable corrosion at the small exposed area of iron, but if anodic, as is the case within tin cans, the corrosion is spread over a large tin area and the iron at the base of the pin hole is galvanically protected.

Cadmium and lead are further examples of metals that reverse their galvanic behavior with respect to iron in certain environments. These examples serve to emphasize that the electromotive series has limited general utility, and are not a reliable index for predicting the galvanic behavior of metal couples in all media.

Organic coatings, including a host

of lacquers and paints, serve largely to isolate the metal from its environment. They are effective on iron to the extent that they limit diffusion of both moisture and oxygen. As electrically insulating coatings, they are being used today in conjunction with cathodic protection as a means for reducing the required current. At any break in the organic coating a current immediately flows to that area and protects the exposed metal. The distribution of protective current is made effective and simple by this combination of protective measures, in contrast to the careful spacing of anodes necessary when the cathode is not coated. Because alkalis are produced at the cathode, it is desirable that organic coatings used in cathodic protection be alkali resistant.

Modern paints incorporate corrosion inhibitors in the paint coating next to the metal (prime coat). These inhibitors serve to limit attack of the metal by any corrosive compounds that succeed in reaching the metal through the organic coating. Common examples of such inhibitors are red lead and zinc chromate, both of which are only slightly soluble in water, yet sufficiently so to bring adequate concentration of the inhibiting ions to the metal surface, where they act to diminish the rate of reaction. Inhibitors of the red lead or chromate type are properly called passivators because they passivate iron, recognized by a more noble potential of the metal in contact with their aqueous solutions.<sup>4, 5</sup> This increased noble potential distinguishes the passivators as a group among the inhibitors. The organic acid pickling inhibitors, by way of con-

trast, alter the potential of iron very little.

#### Inhibitors and Passivators

Inhibitors appear to function by adsorbing on the metal surface, forming a tightly bound monomolecular film or monolayer of ions. The organic inhibitors used in acid pickling of steel contain polar groups that attach themselves to the metal surface. And both through geometry and size of the molecule and through distribution of electric charge, succeed in diminishing the rate at which hydrated hydrogen ions in particular, and probably other ions as well, can reach the metal surface.

The passivators, on the other hand, appear to function by another mechanism. They apparently adsorb more strongly, characteristic of activated adsorption, and satisfy secondary valence forces of the surface. The surface metal atoms in such a state no longer have the same tendency to leave the lattice to enter into chemical reaction. This accounts for diminished reactivity of the metal (reduced corrosion rate) and a more noble potential, as observed. Characteristically, passivators are oxidizing compounds, indicating that they are strong electron adsorbers. Their satisfaction of certain metal affinities is plausibly related to electron adsorption from the metal surface, but is not accompanied by disruption of the metal lattice that occurs with chemical reaction. In addition to their oxidizing characteristics, they are essentially compounds that have a pronounced tendency to react, but do so only slowly because of a high activation energy attending the metal-passivator reaction.

The type of adsorbed monolayer



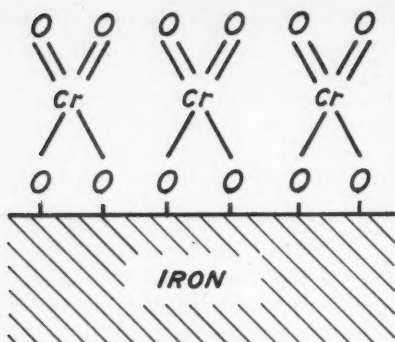


Figure 3—Type of film formed when iron is passivated by chromates.

formed by chromate ions is illustrated in Figure 3. The bonding between the chromate and the metal is chemical, but the metal lattice is intact, and no stoichiometric compound forms.

The organic type inhibitors are now being added to oils and greases used for the protection of surfaces of iron from fingerprinting and accidental rusting during handling or shipping. Recently a volatile organic inhibitor has been produced which fills the air space of packaged steel parts and continuously supplies a protective atmosphere.

### Corrosion Product Coatings

Passivation attended by corrosion-product formation on the metal surface is also common, and represents a type of passivation unrelated to the mechanism described above for passivators, or organic inhibitors. This kind occurs when lead is immersed in sulfuric acid accompanied by a coating of  $PbSO_4$ , or when magnesium is coated by  $MgF_2$  when immersed in  $HF$ , or when silver is coated by  $AgCl$  through reaction with a chloride. Corrosion protection

by such surfaces is obtained purely through a physical barrier layer. (Figure 4). The phosphate and oxide coatings on iron produced by controlled chemical reaction with the metal are in this group. These particular coatings on iron afford of themselves only slight protection because of their inherent porosity. Phosphate coatings, however, serve as an excellent base for paints and aid in the protection that paints provide. Oxide coatings likewise have been found to offer a good structure for the retention of oil or wax on the surface and are corrosion protective when so used.

On aluminum, the oxide coatings formed by anodic treatment (anodized aluminum) offer good protection. They are much less porous than oxide coatings produced on iron. For example, whatever the method employed to produce them, they ordinarily do not require an organic filler to make them impervious. However, they are commonly "sealed" by immersion in a hot aqueous solution which serves to decrease porosity, for example, by hydrating the aluminum oxide. Because of the relatively improved protection

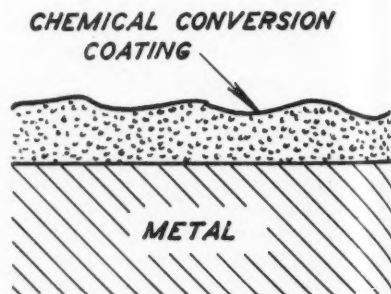


Figure 4—Sketch of a corrosion product layer physically protective to the underlying metal.



offered by such coatings, it is common to anodize aluminum articles subsequently to be exposed to the atmosphere or to aqueous media.

### Alteration of the Environment

Deaeration of water to diminish the corrosion rate of boilers has become general practice. Dissolved oxygen is reduced in concentration by heating water in equipment especially designed for the purpose. For high pressure steam plants, the oxygen concentration must be particularly low, usually less than 0.005 ppm. Modern deaerators can achieve this degree of removal, but should traces of gas remain, the oxygen can be eliminated by addition of sodium sulfite.

For industries using large volumes of cold water, it is often economical to avoid rusting of iron equipment by reducing dissolved oxygen to at least 0.3 ppm. Cold water deaerators are now available to achieve this degree of oxygen removal or better. Water is sprayed into an evacuated chamber and dissolved gasses removed without heating the water above 5° C. (40° F.).

Deaeration, as carried out in modern deaerators, also reduces the dissolved CO<sub>2</sub> content of boiler water and thereby decreases the corrosion rate of steel lines carrying steam condensate. Corrosion of condensate lines is commonly caused by carbonic acid originating from CO<sub>2</sub> or carbonates in boiler water. Corrosion, as with a non-oxidizing acid, is accompanied by hydrogen evolution and the rate can be appreciable. At condensate temperatures, a modern concentration of CO<sub>2</sub> (2.5 ml per liter) causes one-fifth as much corro-

sion of a mild steel as an equal concentration of oxygen.<sup>6</sup>

The addition of lime to low pressure boilers retards evolution of CO<sub>2</sub>, but cannot be used in high-pressure boilers because of scale formation, hence it is necessary to reduce dissolved CO<sub>2</sub> in the feed water of high-pressure boilers. It has been suggested that volatile organic amines added to boiler waters serve to neutralize carbonic acid in the condensate, and can thereby decrease corrosion of condensate lines.<sup>7, 8</sup> The addition of alkalies to boiler water for reducing the general corrosion rate, and the further addition of nitrates, phosphates, quebracho, or similar compounds to counteract possible cracking of severely stressed portions of the boiler by concentrated alkaline boiler water are additional examples of ways in which the environment is altered to reduce corrosion.

An interesting example of corrosion control through treatment of the environment was analyzed satisfactorily only recently. Corrosion in this instance was associated with the amazing effect of the sulfate-reducing bacteria. (*Sporovibrio Desulfuricans*). These bacteria are anaerobic and frequent sea water, certain soils, and the waters of deep wells located, for example, in the Middle West. They accelerate corrosion by depolarizing the cathodic areas of iron and steel, at the same time chemically reducing dissolved sulfates to sulfides. The corrosion they cause is sufficiently intense to cause failure of a galvanized-iron, cold-water pipe in two years. Since they thrive only in absence of oxygen they can be controlled, and in turn the corrosion they cause diminished by aerating

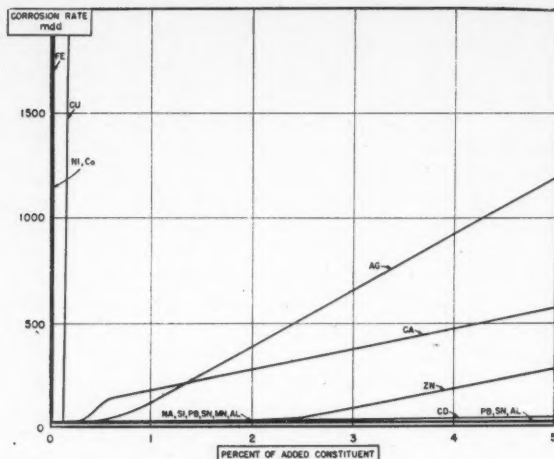


Figure 5—Effects of various alloying elements on the corrosion rate of magnesium in 3 percent NaCl. (W. S. Loose, "Magnesium and Magnesium Alloys," Corrosion Handbook, John Wiley & Sons, Inc. Edited by H. H. Uhlig. In press.)

or chlorinating the water in which they subsist.

### Metal Purification

Purification of a metal so as to remove cathodic elements of galvanic cells entering the corrosion reaction has successfully improved the corrosion resistance of aluminum and magnesium. This approach to corrosion control has not been fruitful for iron. And for good reason, because the corrosion of iron largely depends on the amount of oxygen reaching cathodic areas of the metal. The cathodic areas of iron are not necessarily limited to impurities, but may be portions of the metal surface itself which shift from place to place as corrosion continues and as aeration and other conditions change.

For magnesium, impurities constitute most of the cathodic areas, and purification, therefore, has been beneficial to a large degree. (Figure 5.) In sea water pure magnesium corrodes at a rate of about 0.012 inch penetration per year; whereas commercial magnesium corrodes with

visible hydrogen evolution at a rate possibly 100 to 500 times greater.

Iron and nickel are among the detrimental impurities in magnesium. However, they markedly increase the corrosion rate in NaCl solutions only if present to the extent of more than .017 percent and .005 percent, respectively.<sup>9</sup> The addition of one percent manganese, on the other hand, strikingly reduces the effect of these particular elements. Zinc acts in the same manner as manganese although not quite as effectively. (Figure 6.) The controlled purity magnesium of today, therefore, is pure with respect to certain elements, but more important, it is also judiciously alloyed to counteract the effects of impurities on the corrosion reaction.

Alloying, including surface impregnation, is one of the effective means at our disposal to improve both physical and chemical properties of metals. Surface coatings of silicon-iron alloy produced by reaction of  $\text{SiCl}_4$  with iron are effective in reducing galling of rubbing sur-

faces as well as considerably improving the resistance of iron to many mineral acids. The surface alloy so produced is similar to the commercial 14 percent silicon-iron alloys used as corrosion-resistant castings for equipment in the chemical industry.

The stainless steels are among the most popular of the corrosion resistant alloys. They are iron-base alloys containing at least 12 to 18 percent chromium, and often one or more additional elements such as nickel, manganese, molybdenum, titanium or columbium. They are called passive alloys because they derive their

corrosion resistance by virtue of a property called passivity noted about 150 years ago in connection with iron made unreactive by immersion in concentrated nitric acid. Iron so treated in nitric acid retains passivity temporarily when transferred quickly to other corrosive media. Stainless steels, however, are stable with respect to passivity, and hence are outstandingly resistant to dilute or concentrated nitric acid and to many other media, and are only corroded appreciably by reagents effective in breaking down passivity, such as chlorides.

The mechanism of passivity in

stainless steels is often ascribed to a very thin, continuous, highly protective film of metal oxide, such as  $\text{Cr}_2\text{O}_3$ . It appears more likely that stainless steels and similar alloys, as well as chromium, derive their corrosion resistance by the mechanism that was outlined above for the action of passivators. Their resistance from this viewpoint is inherently the result of diminished chemical reactivity of the metal surface. Satisfaction of secondary valence forces of the metal surface occur through an adsorbed film of oxygen, or of an oxidizing substance that provides for lowered affinity of the metal for its surroundings.

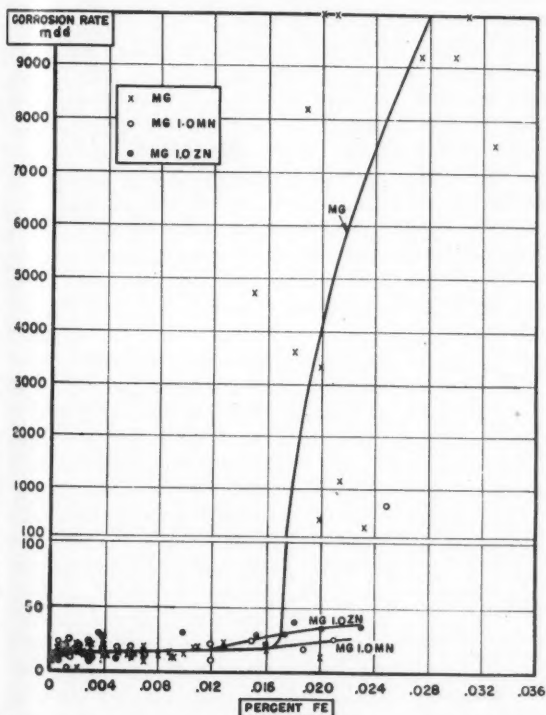
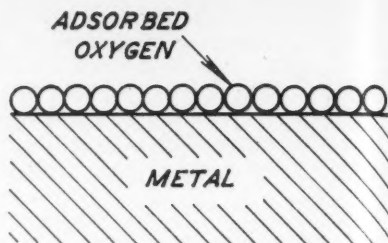


Figure 6—Effect of iron on the corrosion rate of Mg, and Mg-Mn and Mg-Zn alloys in 3 percent NaCl. (W. S. Loose.)

Figure 7—Film of oxygen atoms adsorbed on a metal surface. It is such films that are thought to exist on chromium and stainless steels, accounting primarily for their passivity. A chemical conversion coating (Figure 4) may form under certain conditions additional to this monatomic film.



(Figure 7.) The potentials of passive stainless steels are noble, therefore, as is observed, and the corrosion rate is very low.

The alloying of chromium with iron is accompanied by electron sharing of the two metals, which at or above a critical alloy composition (12 to 15 percent Cr.) imparts to iron the stable passivity characteristic of chromium.<sup>10, 11</sup> The passive range of composition occurs when the ratio of iron to chromium atoms in the alloy is approximately equal to or less than the number of elec-

tron vacancies in the third shell of the chromium configuration. Since there are five vacancies in the third shell of chromium, this critical ratio corresponds to 16.7 atom percent or 15.7 weight percent chromium.

Because passivity in metals is plausibly related to activated adsorption, it appears worth while to consider conditions that lead to adsorption in contrast to compound formation. With some metals it is easier (less energy is required) for an electron to leave the metal in forming a bond with a substance like oxygen, than for the metal atom to leave its lattice to become part of an oxide lattice. The energy of evaporation of electrons from the metal surface is measured by the so-called work function and the energy of evaporation of metal atoms is, of course, the sublimation energy. The ratio of these quantities is a very approximate indication, therefore, of whether adsorption will occur, or whether an oxide coating will form preferentially.

With copper, for example, the ratio of the work function (4.80 volts) to the heat of sublimation (3.54 electron volts), is 1.36, so that one expects copper to oxidize on exposure to the atmosphere. In agreement, electron diffraction experiments prove that oxidation of

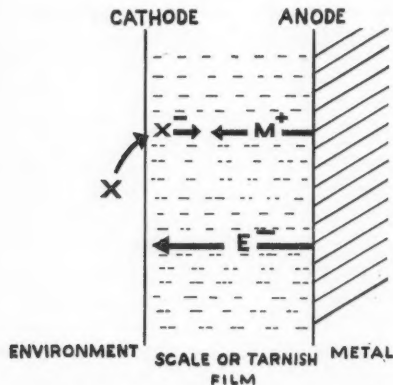


Figure 8—Sketch of a cell operating in a tarnish or oxidation reaction, where the final reaction is  $X + M = MX$ . Metal ions and electrons migrate from the anode surface. Reaction usually occurs at or near the outer surface.

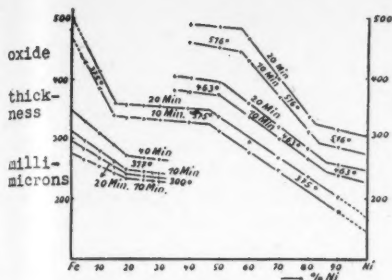


Figure 9—Effects of alloy composition on the thickness of oxide films formed in air on NiFe alloys. (G. Tammann and G. Siebel, *Z. Anorg. Chem.* **148**, 297-321, 1925.)

copper occurs at room temperature.<sup>12</sup> Chromium, however, with a ratio near unity (work function equals 4.35 volts, heat of sublimation equals 3.87 electron volts, ratio equals 1.1), shows no evidence of an oxide film after exposure to air for one week, according to similar electron diffraction studies.<sup>13</sup> Consistent with this observation, ratios of about unity or less are found for the transition metals associated with the property of passivity, and ratios greater than unity for the non-transition metals. This constitutes part of the circumstantial evidence that not a  $\text{Cr}_2\text{O}_3$  coating, but a film of oxygen adsorbed on the surface accounts for the relative chemical inertness (passivity) of chromium. For stainless steels, the situation is thought to be similar, and significantly no attempts to isolate any supposed oxide film have so far been successful. Of course, if the alloy is heated or abraded, the latter process generating high local surface temperatures, an oxide coating forms.<sup>14</sup> However, this oxide coating is not thought to be the primary source of passivity, but is rather an incidental barrier, physically protective and at best not outstandingly effective. It is the adsorbed film that more likely accounts for passivity by reducing surface chemical affinity.

Alloying has been of great value in the development of metals to withstand high temperatures. Here again chromium plays a major role. It is present in all structural alloys that are designed to withstand high temperature oxidation. Other alloying elements useful for high temperature oxidation resistance are aluminum, nickel, cobalt, and to some extent, silicon.

The action of these elements in all but the lower range of temperatures is related largely to their effect on the properties of the oxide coating. According to C. Wagner's work in this field,<sup>15</sup> oxidation is also an electrochemical phenomenon. The cathode of the corrosion cell (oxygen electrode) is at the outer surface

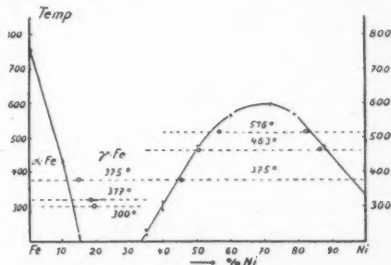


Figure 10—Points at breaks in the curves of Figure 9 plotted on the FeNi phase diagram. The right hand curve is the magnetic transformation curve. The points at the left occur at the transformation or face centered cubic to body centered cubic alloy. (G. Tammann and G. Siebel.)

of the oxide coating and the anode (metal electrode) extends along the metal-oxide coating interface. (Figure 8.) The useful alloying elements in the high-temperature field, therefore, logically decrease either the electronic conductivity of the oxide or the diffusion rate at which the reactant ions move through the oxide, or both.

In the lower range of high temperatures there is evidence that the oxidation rate is limited by the reaction taking place at the metal-oxide interface rather than by the diffusion of reactants through the oxide. Such evidence comes from the marked effect of metal grain orientation and allotropic change in the metal on the oxidation rate<sup>10, 17</sup> and from the changes in oxidation rate of iron-nickel alloys at the Curie temperatures (Figures 9 and 10), the latter being related to electronic transitions in the alloy.

This situation together with that cited for passivity in the stainless

alloys suggests that in building our theories of corrosion, the emphasis so far has been laid too strongly on physical barrier films and coatings as the mechanism of corrosion control. Such films are extremely important in accounting for low basic corrosion rates of many chemically active metals, but the hypothesis that they account for practically all corrosion resistance is not correct, appealing as such a notion might be. It is a mistake, therefore, to encourage the viewpoint that corrosion investigations in general can eventually be simplified to the point where study of the protective film is all that is required, as has been suggested from time to time. Actually the metal and its structure are inherent factors in the corrosion process whether or not physically protective films form on the metal surface. It is probable that this aspect of the problem will receive increased attention in the next phase of fundamental corrosion research.

### References

1. G. Schikorr, *Trans. Electrochem. Soc.*, **76**, 247, 1939.
2. C. F. Bonilla, *Trans. Electrochem. Soc.*, **87**, 237, 1945.
3. Anon., *Aluminum Dipcoated Steel, Materials & Methods*, **24**, 90, 1946.
4. R. M. Burns and H. E. Haring, *Trans. Electrochem. Soc.*, **69**, 169, 1936.
5. H. H. Uhlig and R. B. Mears, "Passivity," *Corrosion Handbook*, John Wiley & Sons, Inc., New York, N. Y. (In press.)
6. G. T. Skaperdas and H. H. Uhlig, *Ind. and Eng. Chem.*, **34**, 748, 1942.
7. F. N. Speller, *Proc. Nat. District Heating Assoc.*, **24**, 203, 1933.
8. M. Dreyfus, *Heating and Ventilating*, **39**, 31-3, 1942. (June).
9. J. Hanawalt, C. Nelson and J. Peloubet, *Trans. AIMME*, **147**, 273-98, 1942.
10. H. H. Uhlig and John Wulff, *Trans. AIMME*, **135**, 494-521, 1939.
11. H. H. Uhlig, *Trans. Electrochem. Soc.*, **85**, 307-318, 1944.
12. A. H. White and L. H. Germer, *Trans. Electrochem. Soc.*, **81**, 305-19, 1942.
13. E. Alessandrini and H. H. Uhlig, unpublished observation. (Hydrogen-fired electrolytic chormium was used, the surface of which had been etched with HCl).
14. W. H. S. Vernon, F. Wormwell and T. J. Nurse, *J. Iron & Steel Inst.*, **150**, 81-92, 1944.
15. T. P. Hoar and L. Price, *Trans. Faraday Soc.*, **34**, 867, 1938.
16. B. Lustmann, *Trans. Electrochem. Soc.*, **81**, 359-375, 1942.
17. A. T. Gwalthmey, "Effect of Crystal Orientation on Corrosion," *Corrosion Handbook*, John Wiley & Sons, Inc., New York, N. Y. (In press).



## Failures of Domestic Hot Water Storage Tanks\*

By Charles P. Hoover

Chief Chemist, Filtration Plant, Columbus, Ohio

EVERY week, according to the Dallas Plumbing Company of Dallas, Texas, more than 12,000 domestic hot water tanks are replaced because they have rusted through. "In no place where metal is employed for domestic use is its wastage so large and extravagant as that caused by the failure of hot water storage heaters."<sup>1</sup> Plumbers called in to repair or replace tanks that have failed in a short time sometimes attempt to explain the failure by saying it is due to "the chemicals in the water." This bit of information often disturbs the consumer, and he usually concludes that water that will eat out a galvanized-iron tank will most certainly ruin his stomach.

If the water supply is not chemically treated, or at the most is only chlorinated, the plumber sometimes points to a nearby trolley line or transformer, which, he says, "leaks electricity into the pipes and destroys the water tank."

Tank manufacturers also have their alibis. They say the failure cannot be the fault of their tank be-

cause "we have thousands in other cities where we never have any complaints, so it must be the water or some other unusual condition for which we are not responsible." It is true enough that cities furnishing water directly from wells usually have a water that is free of dissolved oxygen and high in calcium bicarbonate alkalinity. Such waters are not corrosive, but they do cause excessive scaling in hot water heater coils.

The use of water high in carbonate hardness, however, is not the solution to hot water tank failures. People generally are no longer satisfied with hard water supplies; this is evidenced by the large number of softening plants that have been built in recent years. According to H. M. Olson,<sup>2</sup> there are now 665 municipal water softening plants in the United States.

### Corrosion Control Experiments

In April 1935, experimental corrosion control work on hot water tanks was started at the Columbus, Ohio, Water Softening and Filtration Plant. The work included studies of:

1. The corrosive action of various types of water on galvanized tanks.

\*A paper presented at the Annual Conference of AWAA at St. Louis, Mo., May 7, 1946. Reprinted by permission from the Journal of the American Water Works Association, September, 1946.



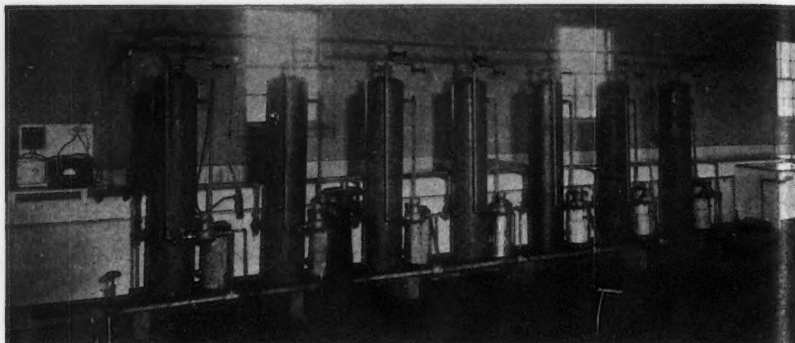


Figure 1—Hot water tanks being tested.

2. Advantages to be gained by adding sodium hexametaphosphate to high pH water.

3. The construction of a cold water deaerator and the operation of tanks with deaerated water.

4. Methods for lining tanks with special cement plastics<sup>3</sup> and the operation of cement or so-called stone-lined tanks.

5. Methods for lining tanks with plastics and the operation of plastic-lined tanks.

6. Construction of a transite pipe hot water storage tank and its operation.

7. Cathodic protection of both galvanized and ungalvanized tanks.

The tanks used were standard 30-gallon capacity types, such as are used in the average home. They were operated so as to simulate, as nearly as possible, actual domestic operation, and the temperature was held at 150° F. Weekly composites of water entering and leaving each tank were collected and analyzed for alkalinity (methyl orange and phenolphthalein) and iron; special samples were also collected and analyzed for dissolved oxygen. The

period of operation of the tanks was from one to two years. At the end of the operation period, the tanks were cut open vertically and examined. In all, 42 tanks were operated and cut open for inspection, and at present there are seven tanks still in service, Figure 1. Representative sections were cut from some of the tanks and microphotographed; from the photographs, the depth of the pits was measured.

### Results of Experiments

It is impossible to include a detailed discussion of the experiments made and the results obtained during the past 11 years. An outline of the work may be found in the annual reports of the Division of Water, Columbus, Ohio, during the years 1935 through 1945;<sup>4</sup> some of the earlier results were published elsewhere.<sup>5,6</sup>

Some very general conclusions drawn from the results of the experiments are:

1. The inherent weakness of galvanized tanks is that they will not give satisfactory service unless the zinc coating holds out long enough

for the water passing through to deposit an incrusting scale of calcium carbonate, or a protective corrosion product. It is, therefore, the scale so formed, which resurfaces the zinc, and not the zinc itself, that affords protection.

2. Cement, or so-called stone-lined tanks give excellent results.

3. Resinous linings are still in the experimental stage. They are not expensive to build, are light, and, if the lining can be made to stick, they should be very satisfactory. Those that were lined for the experiments had a tendency to peel.

4. Cathodic protection proved effective. The tanks soon became coated with a hard flint-like film that could only be removed for analysis by the use of a cold chisel and hammer. This might prove to be a good method for coating tanks. At present the transformer and rectifying equipment is too expensive to make it competitive with higher priced tanks made of stainless steel, monel metal or copper.

A self-activated form of cathodic protection that eliminates the electrical apparatus, however, seems to have been developed by Leonard V. Sutton, who was granted a Canadian patent on May 4, 1943, entitled "Method of Protecting Water Heating Equipment From Corrosion." According to the claims of this patent, cathodic protection may be obtained simply by hanging a strip of metal, higher in the electromotive series than zinc or iron, in the tank.

Experiments are being planned at the author's plant to place a thick rod of magnesium in both a steel and a galvanized tank. Whether these rods, without connection to any outside source of electricity,

will develop enough current flow to the tank walls to afford protection will be determined.

5. The results of the experiments indicate that the addition of polyphosphates (up to 1.5 ppm.) to high pH water, does not appreciably help or retard the formation of a protective calcium carbonate scale in hot water tanks.

Personal observations at a number of water softening plants, as well as the results of the experiments, indicate that galvanizing does not protect steel tanks when the alkalinity of the water is low (20 to 30 ppm.). This applies to natural waters as well as to lime-softened waters. It applies whether the saturation index is negative, neutral, or even slightly positive. Water with a negative index dissolves the zinc and carries it out of the tank as zinc bicarbonate. Water with a neutral or slightly positive index precipitates it as zinc carbonate, which is neither dense nor adherent and therefore provides no protection to the tank.

It should be remembered that low alkalinity water must contain normal carbonates in order to be in chemical balance to calcium carbonate. When such water is heated, enough normal carbonates must be present to produce a high positive index if galvanized tanks are to be protected. At Columbus the index is carried at  $+0.8$ , with a pH value of 10.3. Sodium hexametaphosphate is added (0.35 ppm.) to prevent too much deposit in cold water lines. The coating produced by this supersaturation protects the tank, provided the water is not heated beyond  $150^{\circ}$  F. Since the adoption of this procedure about eight years ago.

very few tank failure complaints have been received.

It is regrettable, however, that these high pH values (10.3) must be carried, as they are not necessary except for the protection of the tanks. The filtering of such water incrusts the filter sand to the point where it must be replaced about every 10 or 12 years. Magnesium compounds, if left in such high pH water—and it is difficult to remove them—slowly precipitate in heater coils and hot water pipes. Unfortunately, good treatment practice must be compromised to protect galvanized tanks from corrosion.

Experiences encountered in army camps,<sup>7</sup> where water is heated to 180° F., demonstrated very conclusively that overheating is probably the greatest contributing cause to premature failure of hot water tanks. Overheating causes corrosion with any kind of natural water, except perhaps when the water is free of oxygen. Merely advocating that temperatures be kept within reasonable bounds is not always effective. Many families have tanks that are too small, and try to stretch the hot water supply by keeping the tank temperature too high. Table 1, recommended by the Pacific Coast Gas Association, gives the tank capacity suggested for homes of various sizes.

**TABLE 1**  
**Tank Capacities Recommended for Homes of Various Sizes**

Number of Bathrooms	Number of Bedrooms	Storage Capacity, Gal.
1.....	1 or 2	30
1.....	3 or 4	40
2.....	2 or 3	40
2.....	4 or 5	50
3.....	3	50
3 or 4.....	4 or 5	75

Galvanized hot water tanks are almost universally used in moderately priced homes because of their low cost and light weight. Despite their long history, however, most water plant operators would welcome a new protective coating that would not appreciably increase the weight and cost of the tank and would not be affected by bicarbonates, normal carbonates or temperatures up to about 180° F.

### Contributing Causes of Failure

In spite of the plumber's opinion that chemicals cause premature tank failures, there are other reasons why tanks fail. Poor tank steel, poor galvanizing and the use of electrochemically dissimilar metals are undoubtedly contributing factors to premature failures of hot water tanks. Each is of sufficient importance to warrant a brief discussion.

### Poor Tank Steel

According to Wallace G. Imhoff, of the American Hot Dip Galvanizers Association,<sup>8</sup> "Defects in the base metal may be of two kinds—chemical and mechanical. There are certain chemical elements, such as phosphorus, sulfur and silicon, that indicate at once whether the steel melting conditions are right or wrong." Scale may be rolled deep down into the steel surface, or steel tanks may be rained on and rust in spots. Due to the heavy rust, it would be very difficult to pickle the tanks properly for galvanizing. Any rust imbedded under the zinc coating may crack or break it and leave the steel exposed to rapid corrosion. Such instances may be unusual, but their existence proves that the char-

acter of the water is not always the cause of tank failures.

#### *Poor Galvanizing*

Fabricating, pickling, fluxing, galvanizing and welding may be faulty and thus contribute to premature failures.

Tanks are pickled in sulfuric acid (6 to 10 percent). The action of the acid upon the steel forms ferrous sulfate. This salt is extremely harmful to the flux solution and to the galvanizing bath. If it enters the bath in large quantities, it not only affects the zinc coating, but forms "galvanizer's dross." The tanks, therefore, must be thoroughly washed after pickling. This precaution is not always taken, for the author has removed a double handful of flux deposit from a new galvanized tank. Zinc ammonium chloride, rather than muriatic acid, is recommended as a flux by the American Zinc Institute, as it has the advantage of producing a better tank coating.

Tin or aluminum is used in the galvanizing bath to brighten the tank; and both, but especially tin, produce spangles which seem to make the tank more attractive to the purchaser. There is an interesting report in the *Journal of American Zinc Institute*,<sup>9</sup> on the premature failure of galvanized steel watering troughs. The report concludes that the presence of tin in the galvanizing bath is an important, if not the most important, factor in the rapid premature failure of stock water tanks.

Forty test tanks, or twenty sets of tanks, located in Minnesota, Wisconsin, Iowa, Illinois, Missouri, Kansas, Nebraska and Colorado were studied. Each set of tanks con-

sisted of one old and one new tank, both supplied from the same water source. The twenty old tanks, which had an average life of 24 years, were still in operation at the end of the test; whereas the new tanks had an average life of only 18 months. Spectrographical analyses showed the only difference in the galvanizing on the old tanks and the new tanks was that the new tanks contained about 1 percent of tin, whereas the old tanks contained only a trace of tin.

The author is not prepared to say that the presence of tin in galvanized hot water tanks is responsible for their premature failure, for he has had only one opportunity to compare the performance of tanks with and without tin incorporated in the zinc. The tank with tin in the coating failed in one year; yet in the author's own home there is a tank that had been in service for 18 years. The tin content of the coating in the new tank was 1 percent; in the old tank there was only a trace of tin. Frankly, the author is suspicious enough to pick a dull tank, if he had to buy a new one, rather than one that was highly spangled with tin.

#### *Dissimilar Electro-Chemical Metals*

Dr. E. P. Schoch, Professor of Chemistry at the University of Texas, testified before the City Council of Dallas, Texas, during their investigation of premature failures of hot water tanks, that, as an electrochemist, he is horrified at the design of the tanks. Copper and iron pipes, zinc, and a liquid solution between them, and the result is a battery cell.

The voltage difference between various cold water inlet pipes or tubes and the metal of the tank

proper has been shown by N. C. Hammer in a report to the City Council of Dallas. The results show that there is a possibility that these inlet pipes, which are of dissimilar metals, will set up galvanic action.

The author knows that galvanizing is not always good for he has personally inspected new tanks and has found bare spots as large as a silver dollar. Although he does not wish to imply that tank failures are always due to poor material, poor processing or poor design, the author does want to contend that failures should not always be blamed on the water. Many tank failures can be eliminated by more careful manufacturing methods.

### Tank Corrosion Prevention

The water consumer as well as the tank manufacturer may also do a great deal to prevent tank failures. The selection of a well-built tank of sufficient capacity would in itself be of considerable benefit. It would also reduce the need of heating the water above the critical temperature of 150° F., which would further contribute to the conservation of tanks.

The various treatment methods that may be adopted will not be discussed in detail; before mentioning them, the author wishes to point out that there is a difference between what *can* be done and what *should* be done in water treatment processes. Tank corrosion can be minimized by:

1. Deaerating the water.
2. Hardening the water so that it will lay down a protective scale.
3. Adding sodium silicate to the water to form a protective scale.
4. Adding polyphosphates to the water.

5. Treating the water so that it is in chemical balance to calcium carbonate or slightly in excess. In other words, carrying a neutral or slightly positive Langelier Index.

6. Supersaturating the water with calcium carbonate to the point where it literally plasters the inside of the tank with calcium carbonate. In other words, carrying an excessively high positive Langelier Index. If this is done, polyphosphates in small quantities should be added to prevent too much deposit of calcium carbonate scale in cold water pipes.

### Deaeration

Results of the experiments indicate that deaeration of Columbus tap water completely eliminates tank corrosion. It would, however, be hard to follow such a practice. Much of the water used in cities is stored in large reservoirs and will reabsorb oxygen from the air during the storage period. Such water would also dissolve any rust in the distribution system. Until the mains are completely cleaned this treatment would plague the consumer with rusty or red water. Also, the expense of deaeration is high. The installation cost is estimated by the Permutit Co. to be \$10,000 for a 1-mgd. plant, and \$200,000 for a 50-mgd. plant. The operating cost is estimated to be about \$2.00 per mil. gal. to reduce oxygen to 1 ppm.

### Increasing Carbonate Hardness

Hardening the water is, of course, undesirable, and some of the supplies on the eastern coast contain too small an amount of free carbon dioxide to be stabilized. To stabilize water of this kind requires both lime and carbon dioxide unless the treat-

ment is carried to the point of causality. Frank E. Hale, of the New York City Water Dept., has stated on numerous occasions that he is opposed to hardening the Catskill supply, one of the softest municipal water supplies in the country. He has always recommended that the customers use the best plumbing material available for this kind of water, and stresses particularly that it does not pay to buy cheap material for extensive use.

#### *Use of Sodium Silicate*

It seems unreasonable to expect a water department to treat its entire supply with sodium silicate simply to prevent corrosion in hot water tanks. This chemical forms scale in the mains and extra silicate in the water may be objectionable to operators of steam boilers. Unless needed to prevent corrosion in the distribution system, it should not be used.

#### *Addition of Polyphosphates*

The experiments indicate that the addition of polyphosphates, up to 1.5 ppm., to high pH water, that is, water that is stabilized or highly supersaturated with calcium carbonate, does not appreciably help or retard the formation of a protective calcium carbonate scale in hot water tanks.

#### *Chemical Balance to Calcium Carbonate*

The experiments also show that low alkalinity water (25 to 30ppm.) which is in chemical balance to calcium carbonate is very destructive in hot water tanks. The walls of the tanks become partly covered with calcium carbonate, but numerous corrosion spots develop and corrosion concentrates at these points. The tank is apt to develop leaks more quickly than when the corrosion is more uniform throughout the entire area of the tank. Figure 6 of a previous paper by the author<sup>10</sup> shows a tank that was operated for one year with water of this composition passing through it.

#### **Conclusions**

Galvanized tanks have a long history behind them; they are cheap, easily installed and well established in the trades. They will undoubtedly be used for some time to come, but probably will be replaced, eventually, by something better. Until then, the water treatment plants, the manufacturers and the home owners should co-operate to the utmost in eliminating, or reducing, the excessive waste now caused by the failure of hot water tanks.

#### **References**

1. Chris. Goldkamp, Corrosion of Hot Water Storage Heaters. Gas Mag. (Feb. 1946).
2. H. M. Olson, 1944 Census of U.S. Municipal Water Softening Plants. Jour. A.W.W.A., 37: 585 (1945).
3. Anon. Cement Lining Salvages Hot Water Tanks. Eng. News-Rec., 131: 406 (1943).
4. Annual Reports, Division of Water. Columbus, Ohio (1935-1945).
5. Charles P. Hoover, The Corrosive Action of Various Types of Water on Household Plumbing. W. W. & Sew., 83: 384 (1936).
6. Report of the 20th Ohio Conference on Water Purification. P. 96 (1940).
7. Lewis H. Kessler, V. Bruce Sundstrom, & Arthur O. Tomek, Water Supply Practice in Army Training Centers. Jour. A.W.W.A., 35: 1009 (1943).
8. Private Communication.
9. G. C. Bartells, Tank Tests—Progress Report. Jour. Amer. Zinc Institute, 21: (1940).
10. Charles P. Hoover, Stabilization of Lime-Softened Water. Jour. A.W.W.A., 34: 1441 (1942).



## Corrosion of Galvanized Hot Water Storage Tanks\*

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IN the following discussion of galvanized hot water storage tanks, it is assumed that all corrosion is electrochemical under the conditions existing in a hot water system. Electrolytic corrosion in water is the result of two simultaneous reactions: the solution of the metal in the form of metal ions at the anode, and the liberation of an equivalent amount of hydrogen by reduction of hydrogen ions at the cathode. These reactions involve the flow of electrons from the anode to the cathode through the metal. The solution of the metal at the anode results in a film of solution which is relatively concentrated with respect to the metal ion; and increasing ionic concentration of the film causes the anode to become more electropositive, that is, its tendency to go into solution becomes less. At the cathode, liberated hydrogen acts as a hydrogen electrode, and the hydrogen ion concentration in the cathode film is reduced, due to the formation of atomic hydrogen. This change in hydrogen ion concentration results in a reduction of the cathode potential.

These two potential changes are known as anode polarization and cathode polarization, respectively. The corrosion rate is proportional to the current flow and is decreased when polarization reduces the potential difference between the anode and the cathode.

The limiting concentration of the metal ion is dependent upon the solubility product of the hydroxide, carbonate, or basic carbonate, or other insoluble corrosion products. The precipitation of insoluble films of these corrosion products will reduce the corrosion rate by mechanically restricting the diffusion of the products of corrosion from the surface and preventing the access of fresh corrodent to the surface of the metal.

When galvanized steel corrodes in water containing bicarbonates, zinc carbonate is produced at the anode and calcium carbonate is electrochemically precipitated at the cathode. Corrosion ceases when a complete film is obtained. In hard water, this occurs in a comparatively short time and results in good service life of the hot water storage tank.

The prime factor in controlling the corrosion rate in water is the

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depolarization of the cathode film of hydrogen. In acid solutions, this is accomplished by mechanical removal of the hydrogen as gas bubbles. In potable water containing dissolved oxygen, the hydrogen film is depolarized by oxidation. If air-free water could be obtained, then, there would be no corrosion problem. A test reported by Hoover,<sup>1</sup> using deaerated water in a range boiler, showed no corrosion, with iron-free water during the one-year test.

In order to simplify the various factors involved in the corrosion of galvanized hot water storage tanks, they may be classified as either internal or external factors. The internal factors are those inherent in the materials, and can be controlled by the manufacturer. The external factors are those which the manufacturer cannot control. Internal factors include the steel, zinc, proper cleaning, fluxing and galvanizing practice. The galvanic protection of the steel by the zinc coating is an inherent property of the materials and may be considered an internal factor.

#### Internal Factors

The steel used for the construction of the tanks is generally a low carbon, basic open-hearth, rimmed, hot-rolled sheet. The analysis conforms to Society of Automotive Engineers' specifications 1010 or American Iron and Steel Institute's C 1010 specifications. This type of steel is used because it presents the most desirable surface for galvanizing. It can readily be formed into tank heads and bottoms and can be welded by automatic machines.

In regard to the effect of the analysis of open-hearth steel on corro-

sion, Speller<sup>2</sup> states: "This metal is used for galvanizing, enameling, electrical apparatus, roofing material, wire and other purposes where a very ductile form of highly pure iron is desired. At one time, some investigators felt that iron of such high degree of purity was the main solution of the corrosion problem. These expectations have not been altogether realized, as tests and experience seem to indicate that in most cases extreme purity is not so important as other considerations."

The most common tramp alloy found in steel today is copper. In regard to its effect on under-water corrosion Speller<sup>2</sup> states: "As a rule, the addition of copper to steel appears to have no decided influence one way or the other when the metal is exposed under water or in the soil."

The zinc commonly used for hot dipping conforms to the ASTM Specifications<sup>3</sup> for Prime Western grade. The effect of various alloying metals on the corrosion rate of zinc in half-normal sulfuric acid has been shown to accelerate corrosion except in lead, aluminum and mercury.<sup>4</sup> The effect of these alloying elements on the corrosion rate of zinc in potable water has not been determined. The data cannot be extrapolated from half-normal acid to hot water because depolarization in the acid is by hydrogen evolution, whereas in water the depolarization is primarily due to dissolved oxygen. McKay and Worthington<sup>5</sup> state: "In spite of this evidence of the positive effect of impurities, however, it was generally true that variations in the type and quantities of impurities as they exist in sheet zinc and zinc coatings

carry no virtual demonstrated significance from the corrosion angles."

The conclusion that tin in the zinc coatings will cause rapid failure in hot water tanks is not warranted from observations of stock watering tanks. Corrosion data obtained under one set of conditions cannot be applied *per se* to corrosion occurring under entirely different conditions where other external factors control the corrosion rate.

Although considerable data have been obtained regarding the mechanical properties of zinc coatings alloyed with various metals, no data have been found concerning the effects of these alloys on the corrosion resistance to hot water. It may be found that some zinc alloy coating will offer greater service due to the properties of the corrosion product film.

The third and very important factor which can be controlled by the manufacturer is the correct preparation of the steel and galvanizing pot operations. The sequence of operations includes: (1) the removal of grease and oil from the steel; (2) the pickling of the steel to remove all oxide or scale from the hot-rolling and welding operations; (3) a thorough rinsing to remove all acid and iron salts; (4) a dip in muriatic acid or preferably a zinc chloride ammonium chloride flux; (5) drying; (6) immersion in molten zinc maintained within proper temperature limits; (7) withdrawal from molten metal and cooling.

Control of the cleaning, pickling and flux bath is mandatory for good results. With the wartime development of electroplated coatings on steel, considerable research has been conducted on metal cleaning. It can

be expected that this knowledge will be applied to the cleaning of metals prior to hot-dip coating.

Cleaning of the tank after tapping to remove the cuttings is necessary to prevent local oxygen concentration cells and premature pitting of the bottom of the tank.

### External Factors

The "external factors" are those which influence the corrosion rate but which cannot be controlled by the tank manufacturer. These external factors include the variation in water supply, the rate of flow of water through the tank, the temperature of the heated water, rate of heating, pressure variations, and the introduction of galvanic couples by the use of brass or copper pipe or fittings. One of the factors controlling the corrosion rate is the depolarization of the cathode by dissolved oxygen. The amount of oxygen introduced into the hot water storage tank will be in proportion to the volume of water drawn from the tank and the quantity of dissolved oxygen present in the water.

The influence of temperature on the corrosion rate is exerted in five simultaneous ways. The first effect of temperature is to increase the rate of the chemical reactions which constitute corrosion. The second effect is the thermal softening of the water by decomposition of the bicarbonates to normal carbonates and the formation of scale on the heated surfaces. The softened water will be more aggressive than the original cold water when held in the storage tank.

A third effect of temperature is a reduction in the pH of the water. This may be further intensified by

the release of free carbon dioxide from the decomposition of any bicarbonates present. The fourth effect of temperature is the dimensional change of the tank resulting from expansion of the metal when heated and from the increase in hydrostatic pressure resulting from the heating of the water. Pressure release valves will limit this latter effect. This breathing of the tank, if excessive, will loosen or crack the protective scale or film and expose bare metal to the action of the water. The fifth effect is the change in the nature of the corrosion product film. Cox<sup>6</sup> has investigated the attack on zinc by distilled water and concluded that the nature of this film, that is, whether the film is gelatinous and adherent or granular, flaky and non-adherent, controls the rate of attack.

The rate of heating and the method of application of heat to tank also influence corrosion. If large volumes of hot water are required intermittently, the proper procedure would be to install a large storage tank to meet the peak demands, and to heat the water at a moderate rate during the off-peak time. The usual household practice, however, is to increase the temperature of the water by changing the setting of the thermostat. The resulting over-heated water is then mixed with cold water at the tap to give a large volume of water at the desired temperature. This practice produces red water and greatly reduces the service life of the tank.

A moderate rate of application of heat will reduce the amount of thermal softening and scale formation. Since the scale acts as an insulator on the heating surfaces, it will reduce the rate of heat transfer to the

water. This is usually offset by an increase in the size of the flame to give a higher temperature difference. The cycle is repeated until an excessive amount of red water is obtained or until the heater fails to operate because the passages are closed by the scale.

The use of a horseshoe burner directly under a range boiler may reduce the life of a tank to as low as one of two years, because of local overheating. In a test at Columbus, Ohio, the galvanized range boiler heated by a burner below the tank failed in less than a year and a half, while other similar tanks which were heated by sidearm heaters showed no pitting after a two-year test<sup>7</sup>.

The effect of pressure variations when caused by increase in temperature has been described. Pressure variations due to line conditions or water hammer will also cause a loosening or cracking of the protective film.

The use of copper or brass for cold water dip tubes, heater connections and thermostats is general practice. This introduces the galvanic couple where the copper or brass is protected at the expense of the steel or zinc; however, corrosion of the tank is not greatly increased because of the small area of brass or copper in comparison with the larger area of galvanized steel<sup>8</sup>. Where copper or brass pipe or tubing is used with a galvanized steel tank, this area ratio of anode to cathode areas becomes unfavorable; however, the effective cathode area is still small and only a slight increase in corrosion is noted. Galvanic corrosion resulting from the use of copper pipe can be controlled by the use

of insulating reducing bushings. It is recommended that all hot and cold water and gas lines be insulated from the tank with such bushings. One precaution must be observed if insulating bushing are used: the pipe must not be carrying an electric current. The flow of an electric current across an insulated pipe joint will result in intense local attack at the end of the pipe where the current leaves the metal and passes into the water.

The service life of galvanized hot water storage tanks has been the subject of many conflicting opinions. Wallace G. Imhoff, Technical Director of Research for the American Hot Dip Galvanizers Association, when asked why there is an increase in the failure of water tanks and heaters, said: "From my thorough study of this subject I am inclined to believe that the basic cause is the deterioration in the quality of the steel base."

The steel industry points out that the quality of the steel is better today than that obtainable 20 years ago because of improvements in equipment and instruments which afford more accurate controls of analysis, temperature and rolling conditions.

On the other hand, a representative of the New Jersey Zinc Company Research Division stated<sup>9</sup>: "It is our belief, at the present time, that the problem of corrosion of galvanized hot water containers is best solved by the control of the water itself."

The conflicting statements just presented were not intended to add to the confusion, but rather to show that different interests approach the problem in various ways.

Probably the most satisfactory explanation is offered by Evans<sup>10</sup> who describes the anodic protection of steel by the zinc coating and the cathodic film resulting from the deposition of calcium carbonate. Evans states: "The argument may explain why, in recent years, failures of galvanized hot water systems appear to have become more frequent. There is no reason to think that the zinc coats are sensibly thinner or that manufacturing skill has declined; but the water enters the tank or cylinder in a softer condition because the more efficient heating furnace, designed to meet the popular demand for hot baths on short notice, causes a considerable amount of softening in the boiler or in the pipes."

### Summary

The internal factors which can be controlled by the manufacturer of galvanized hot water tanks are the steel and the zinc, and the preparation of the surface prior to galvanizing. The latter may be the most important internal factor with regard to service life. Changes in the analysis of the steel and zinc may give an increase in service life due to the properties of the corrosion product film. Tests have been conducted which indicate that increased resistance to pitting may be obtained by changing the coating<sup>11</sup>.

The external factors were the quality of the water, rate of flow through the tank and, perhaps the most important factor of all, the temperature of the water and the rate of application of heat. Other external factors are pressure variations and galvanic couples formed by copper or brass pipe used with galvanized steel tanks. The use of nonfer-

rous pipe or tubing has been a comparatively recent practice and may accelerate the apparent reduction in service life of galvanized tanks.

In line with the above discussion, the following recommendations are offered:

1. Select a tank of suitable capacity to meet maximum requirements of "usable" hot water.
2. Use heavy gage material to restrict mechanical "breathing" of the tank.

3. Insulate the tank so as to permit the lowest rate of heating.

4. Use a thermostat to limit the maximum water temperature.

5. Use a pressure relief valve to limit maximum water pressure.

By following these recommendations, one can obtain the maximum service life. In the final analysis, it is the maximum service life per dollar spent that is the solution to any corrosion problem.

### References

1. C. P. Hoover. City Bulletin of Columbus: Annual report, Division of Water, Columbus, Ohio (1943).
2. F. N. Speller. Corrosion, Causes and Prevention. McGraw-Hill Book Co., Inc., New York (2nd ed., 1935).
3. A.S.T.M. Standards: Part I, Metals. Standard Specifications for Slab Zinc (Spelter): A.S.T.M. Designation B 6-37. American Society for Testing Materials. Philadelphia, Pa. (1940).
4. C. J. Smithells. Impurities in Metals. John Wiley & Sons, Inc., New York (2nd ed., 1930).
5. R. J. McKay and R. Worthington. Corrosion Resistance of Metals and Alloys. Reinhold Publishing Corp., New York (1936).
6. G. L. Cox. Effect of Temperature on The Corrosion Rate of Zinc. Ind. Eng. Chem., **23**: 902 (1931).
7. E. H. Thwaites. Metaphosphate and Cathodic Protection Research. A.I.S.I. Report PR 102A. Columbus, Ohio.
8. W. A. Wesley. Controlling Factors in Galvanic Corrosion. Proc. A.S.T.M., **40**: 690 (1940).
9. Abstract Reports of Research Division of New Jersey Zinc Company (Jan. 12, Feb. 16, 1944).
10. U. R. Evans. Metallic Corrosion, Passivity and Protection. Edward Arnold & Co., London (1937).
11. J. M. Bialosky. Unpublished data.

### Discussion

*By Owen Rice*

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The use of a zinc coating for protecting iron is very old, and galvanizing has long been an established practice in the industry. The very term "galvanizing" is itself indicative of one of the principal reasons for this use of zinc—the galvanic action which causes the zinc, rather than the iron, to corrode. Thus the

zinc coating continues to protect the iron even after it has been penetrated. In addition, of course, zinc is usually corroded by water less rapidly than iron, and its corrosion products, which are white, are less objectionable than is iron oxide.

Galvanizing affords excellent protection against atmospheric corro-



sion. It is this writer's opinion that galvanizing made its reputation in such service, for the long life of galvanized roofing and galvanized wire fencing is well known. The length of life of galvanized hot water tanks, however, is extremely variable—it varies from less than one year in many localities to 30 or 40 years in others. Where the life expectancy is short, what might be called the useful life of the tank is even shorter, because long before the tank wall is actually penetrated the zinc will have been removed, and discoloration of the water with iron rust will have rendered the water almost unusable for washing.

Unfortunately, the water that is least corrosive in galvanized hot water tanks is water that is hard and high in bicarbonate content, forming a protective scale of calcium carbonate over the entire tank wall. Of course, no one likes hard water, and almost everyone will prefer a naturally soft or an artificially softened supply even though corrosion of galvanized hot water tanks results. This is less extravagant than it may sound, even neglecting the effect of hard water on increased soap consumption, because it is probable that a water that will form enough scale to protect the inside of a hot water tank will also form so much scale that the heater coil will have to be replaced at frequent intervals, thus causing the householder almost as much trouble and expense as is involved in renewing a tank. Naturally, all of us want to have our cake and eat it too, and therein lies the problem. How to protect galvanized hot water tanks from the corrosive action of natural or artificially softened water supplies.

As soon as we attempt to treat the water in order to lengthen the life of the galvanizing, we encounter another dilemma. The galvanic action of a zinc coating requires the sacrifice of this metal as the fee for the protection of any exposed iron. If we treat the water solely to protect the zinc, we tend to destroy the sacrificial action of this metal; we now rely upon the zinc solely as a coating, such as a paint film, to insulate the water from contact with the ferrous metal. Unfortunately, we cannot hope to do so perfect a job of protecting the zinc as to insure a very long life for a galvanized coating, which must be relatively thin (if thicker than 0.003 in., the zinc will flake and peel off the iron surface). Once penetration of the zinc coating occurs, conditions are very similar to those existent at a pin-hole in a painted steel surface; the oxygen content of the water is high, since little has been consumed by attack upon the protected galvanized surface, and conditions are ripe for extremely rapid attack upon the limited area of steel laid bare by the perforation in the galvanized coating. As a result, rapid penetration of the base metal of the tank occurs with the formation of a pin-hole leak; whereas, if the zinc had not been so well protected, the area of attack would have been widened and the failure delayed. And right here is where poor galvanizing enters the picture, for many cheap tanks have large spots bare of zinc when installed. In one examination of the stock in a warehouse of a leading wholesaler, it was found that 79 out of 80 tanks showed bare spots. For this reason, it is often possible for galvanized hot water tanks to

fail more rapidly with water conditions which should give the maximum protection to zinc than with waters which are actually far more corrosive to the galvanized coating.

Thus, in practice the problem of protecting galvanized tanks resolves into the problem of protecting the base metal, steel.

High pH, which tends to produce a pitting attack upon steel, is apt to lead to an even more severe localized attack of galvanized tanks by lowering the protective galvanic effect of the zinc coating. Unfortunately, lowering the pH of an uninhibited water, which would probably create a red water problem, is not practical, even though it would make corrosion more uniform and prolong the actual life of the tank. The pitting action resulting from high pH forms the basis for this writer's recommendation that the best results for corrosion control with Calgon (sodium hexametaphosphate) can be obtained at neutrality or slightly below (pH 5 to 7); actually, approximately the same degree of corrosion inhibition can be attained with Calgon at high pH values, but what attack does occur is of the pitting type characteristic of this high pH range.

In a softening plant where, in effect, the water is already of high pH, it may prove satisfactory to keep the pH up as recommended by Hoover. The writer believes, however, that a minimum value of 10.4, considerably higher than is customary, is desirable, since the corrosion rate of both zinc and steel drops rather markedly as the pH increases above 10.4. This point is still to be decided but, at any rate, the writer believes that the pH range of 8.0-9.5,

which generally includes the stability pH, is apt to be the most damaging of all, even though "red water" is decreased; for the pH in this range is neither high enough to give protection nor low enough to avoid localizing the attack. Moreover, there is usually not enough calcium carbonte to form an effective scale coating on the walls of the tank. Confirmation of this opinion is indicated by the results reported by C. F. Bonilla, Professor of Sanitary Engineering at Johns Hopkins University<sup>1</sup>.

A high pH has one important advantage that seems to have been overlooked. Much has been said of the deleterious galvanic effect of a copper drop tube in a hot water tank. To this the writer can only say that he has examined many tanks that have failed and has yet to see one where the pitting was pronounced near the copper-zinc-iron junction, where failure should occur if the copper pipe were a contributing cause.

On the other hand, no mention has been made of the action of minute amounts of dissolved copper. This action is very deleterious to zinc and so would cause a rapid failure of the galvanizing. Table 1 shows the influences of dissolved copper and Calgon upon zinc strips suspended in Pittsburgh tap water (pH 6.5) at room temperature for five days.

The pronounced effect of only 0.2 ppm. of dissolved copper is clearly indicated. High pH, to the extent that it prevented solution of the copper, would thus be advantageous.

Another important effect of Calgon in protecting galvanized hot water tanks, is that it inhibits the



**TABLE 1**  
**Effect of Dissolved Copper on Zinc**

Copper Content ppm.	Zinc Weight Loss mg./sq. dec./day		
	Calgon ppm.		
	0.0	5.0	10.0
0.01.....	32.3	12.2	8.7
0.2.....	105.0	21.5	10.0
0.5.....	116.0	16.9	71.1
1.0.....	119.0	71.1	18.5

attack upon the steel. Reducing the attack on the steel makes sacrificial corrosion of the zinc unnecessary. It thus inhibits the attack upon the zinc without losing the protection of galvanic action for any bare steel which may be exposed in the system. Table 2 shows the protection afforded by Calgon to coupled zinc and steel plates of equal areas when exposed to Pittsburgh tap water (pH 6.7) at 176° F.

The relatively high feed of 5 or 10 ppm. of Calgon which seems to be required to protect hot water tanks is made necessary by the more corrosive conditions under which basic zinc carbonate and iron oxide which adsorb Calgon from solution are generated more rapidly. Also, the lack of turbulence in the tank and the low volume of water used per day, in comparison with the area of metal exposed, tend to reduce the amount of Calgon actually reaching the surface of the metal where it can be adsorbed and exert its protective action.

**TABLE 2**  
**Effect of Calgon on Corrosive Galvanic Action**

Calgon ppm.	Weight Loss mg./sq. dec./day	
	Steel	Zinc
	Plates Separated—No Contact	
0.....	1270.0	20.5
	Plates Coupled	
	374.0	144.0
	5.....	1.3
	10.....	0.4
	25.....	0.4

To date no city has used a sufficient feed of Calgon to afford adequate protection to the hot water tanks of the consumers. Such quantities of a similar glassy phosphate, Micromet, have been supplied to several thousand hot water tanks, particularly in Little Rock, Ark., and Dallas, Texas, since 1942. But just how long such treatment will prolong the life of a galvanized tank is still unknown, since at this writing no new tank treated with Micromet has yet failed, even though identical untreated tanks continue to fail at intervals of one to two years. From the laboratory data given above, at least a tenfold prolongation of the life of these hot water tanks might be expected from such treatment. The writer does not consider the cost of such treatment to be excessive.

### Reference

1. C. F. Bonilla, Pipe Service Tests on Baltimore Water. Trans. Electrochem Soc., **87** (1945).

## Preparation of Metals for Painting—A Review\*

*By R. E. Gwyther*

Technical Service Department, Sherwin-Williams Company, Cleveland, Ohio

**P**AINT is widely used and very effective means of protecting metals from atmospheric corrosion. Paint protects metals in two ways: by separating the metal from its corrosive environment (such protection is not perfect because paints known today are not completely impervious to moisture and oxygen), and by the use of inhibitive pigments, which provide protection when the paint is penetrated by corrosive elements.

Despite this dual nature of paint protection, even the best of paints, if applied to an improperly prepared surface, may fail to give the desired degree of protection. Too, some corrosion problems cannot be met by paint alone.

### Metals Must Be Clean

In practice, metals are covered with films of materials such as: corrosion products, mill scale, rust-proofing oils, surfacing compounds, dirt, grease, etc. This layer can be wet by paint, but may itself lack adhesion to the metal. Small quantities of oil and grease and even finger-

prints, will prevent adhesion between the paint and the metal. Paint which does not have good bond to the metal tends to blister when exposed to moisture. Blistering is aggravated by the osmotic effect of water soluble materials present on the metal surface. It is true that some surface products, such as thin, tightly adherent scale are not objectionable and may even be a good base for paints. In general, however, all foreign materials must be removed from the surface of the metal before painting. After cleaning, a metal can be quickly tested for cleanliness by simply rinsing with cold water. If the metal surface supports a continuous water film, it is considered reasonably free from oils, greases and insoluble soils. The test is occasionally obscured by the presence of hydrophilic wetting agents, which may permit a break-free water film even when grease is present. Rinsing before cleaning will detect the presence of such an agent.

### Simple Cleaning Methods

There are several methods for cleaning sheet or other smooth metal surfaces. A widely used but unde-

\* A paper presented at the Modern Metal Protection Symposium, Cleveland, Ohio, September 21, 1946.

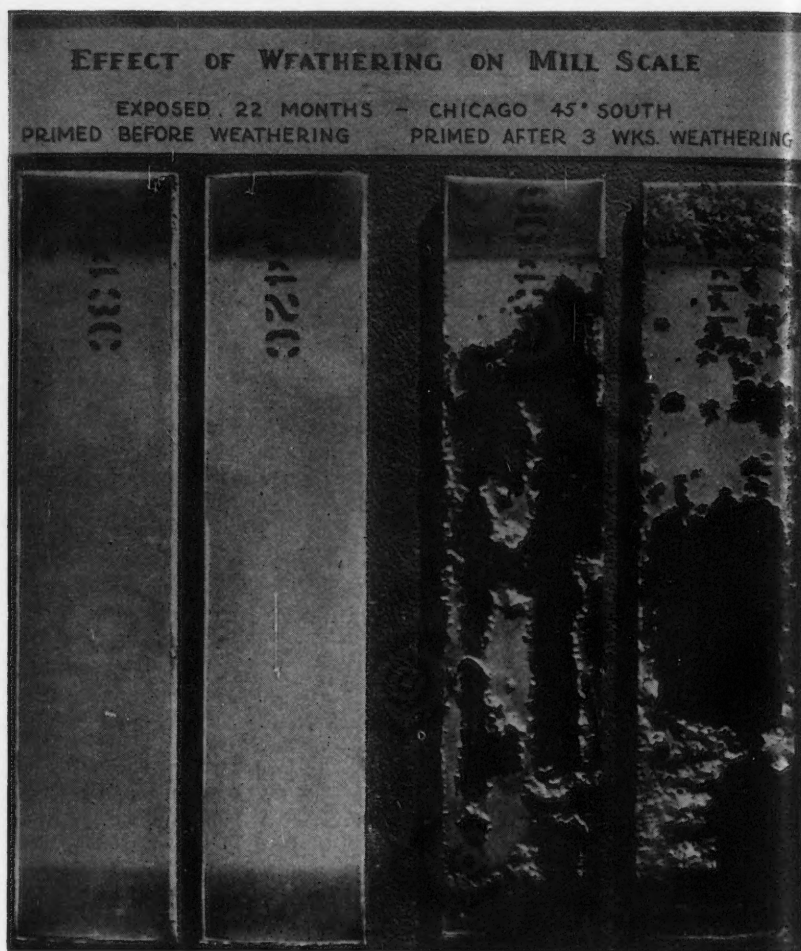


Figure 1—Illustrating the effect of weathering on mill scale. Panels at right were exposed three weeks, then wire-brushed to remove loose scale prior to painting. Panels at left were painted before exposure. The entire groups of panels were given one coat of synthetic zinc chromate primer and a coat of synthetic paint and then exposed 22 months at the Sherwin-Williams laboratory in Chicago. Panels at left remained in excellent condition while Panels at right were failures due to the effect of corrosion products remaining on the surfaces before painting.

pendable method is to wipe the metal with rags soaked with petroleum or aromatic solvents. Unless considerable quantities of clean cloths are used, much of the grease is not removed, but is smeared over the entire surface. Spray application of the solvent is more effective; the fire hazard is bad, but probably no worse than that of large quantities of solvent-soaked rags.

For test panel cleaning, a mixture of naphtha and xylol has been used as a spray solvent with considerable success. The procedure is to spray the solvent with an ordinary paint spray gun, with atomization jets nearly closed, from an acute angle, just as you would clean dirt and leaves from a sidewalk with a garden hose.

An important application of solvent cleaning is vapor degreasing, using the non-inflammable solvents, trichloroethylene or perchloroethylene. For stubborn soils, immersion or spraying methods may be used, the final cleaning in any case being in the vapor phase.

The metal is hung in vapors of the boiling solvent. Clean solvent condenses on the metal so long as the metal temperature is below the dew point of the vapor. At equilibrium temperature, the metal is removed from the vapor dry. Chlorinated solvents must be stabilized to prevent dissociation, under certain conditions forming products which stimulate corrosion.

Alkaline cleaners consist of alkaline salts plus soaps, detergents, clays, etc., usually sold under proprietary brands. They are used in hot, dilute aqueous solution, by immersion or by spraying. Animal and vegetable oils are removed by sa-

ponification, and mineral oils and insoluble matter by emulsification or colloidal action. Highly caustic cleaners should be used for ferrous metals only.

Alkaline cleaners are low cost and very effective cleaners. Efficiency can be increased by application of electric current, making the object the cathode. Alkaline cleaning must be followed by very careful rinsing, because any alkaline residue will react with saponifiable portions of the paint, destroying paint adhesion.

Emulsifiable cleaners contain grease solvents plus soaps and detergents to give better emulsification and rinsing qualities. This concentrate is mixed with kerosene for use. It is sprayed, dipped or brushed on the metal and allowed to stand until it penetrates the soil. Then they may be rinsed off with water. A milky emulsion is formed during the rinse. The chief advantage of emulsion cleaners is flexibility of use.

In removing corrosion and scale from heavy metal by scraping, wire brushing or sanding by hand, results are limited and depend on the care of the operator. Powered processes such as wheel or belt grinding or rotary wire brush are more effective. A roughly sanded surface is known to be of irregular activity and subject to corrosion; this is not true of prolonged fine sanding. Blasting with sand, shot or grit produces a chemically clean surface. A blasted surface must be painted before corrosion occurs.

Active metals such as magnesium if shot-blasted must be pickled to remove electro-positive particles. A recent development in blasting technique includes the addition of rustproofing chemicals to the abra-

sive, to produce passivation and cleaning simultaneously.

Pickling is widely used to remove scale and corrosion products. In the case of steel, hot dilute mineral acids are used, with inhibitors to minimize the attack on the unoxidized metal. The method is low in cost and effective. Disadvantages are flash rusting after pickling (which can be controlled by a dilute chromic acid rinse) and loss of metal weight.

Electrolytic pickling in molten caustic or in molten salts is used for removing mill scale and other corrosion products from steel. These methods produce clean and uniform surfaces and are said to be free of some disadvantages of acid pickling. When used prior to painting, care must be taken to rinse all traces of alkaline materials from the metal.

Flame cleaning is used to remove scale by extremely rapid heating, followed by rapid cooling. Differences in expansion cause the scale to break away from the underlying metal. Flame cleaning is also used to remove condensed moisture from structural steel prior to painting.

#### **Chemical Treatments For Iron and Steel**

Rust removal is of primary importance in painting iron and steel. Paint applied over rust will usually blister when exposed to moisture, because moisture causes rust to swell. Corrosion once started under a paint film spreads rapidly.

Phosphate treatments are the most successful treatments for iron and steel prior to painting.<sup>1</sup> The phosphate solution consists of an aqueous solution of phosphoric acid saturated with phosphates of the metals (iron, manganese, zinc, or cadmium), plus an accelerator. Iron

or steel immersed in the solution at near boiling temperature from one to five minutes is coated with metal phosphates, which are crystalline and chemically united with the metal surface. Phosphate coatings are insoluble, passive to corrosive reactions, abrasion resistant, and adherent. They provide an excellent base for paints, and prevent spread of corrosion under the paint film.

A typical production sequence for phosphating follows:

- (1) Alkaline clean
- (2) Rinse
- (3) Rinse
- (4) Hot phosphate dip or spray
- (5) Rinse
- (6) Dilute chromic acid rinse

Phosphoric acid cleaners consist of phosphoric acid plus grease solvents (such as alcohols), and other ingredients. When applied in a process similar to that described above, they produce an amorphous coating at lower cost, but with less corrosion protection than the phosphate method.

An amorphous coating permits better paint gloss than the crystalline coating. Phosphoric acid cleaners are also used for simpler methods of application, such as the brush-on, wipe-off method, which combines cleaning and passivation in one operation. Protection afforded by these cleaners is variable depending on constituents. In any case they accomplish removal of rust.

Phosphoric acid cleaning in general should be followed by rinsing. Gelatinous residues in particular must be removed before painting. Chromic acid in very dilute solution is used as a final rinse after phosphating. The acid rinse insures that the metal is not left alkaline from

industrial rinse waters, which would preclude good paint adhesion. Chromic acid rinse, as a single treatment set down as follows, has been found to have considerable passivating effect on iron and steel:

- (1) Alkaline or emulsion clean.
- (2) (3) Rinse cold and hot.
- (4) Rinse in hot dilute chromic acid, or in some cases dilute chromic and phosphoric acids.

We have found that for maximum resistance to blistering in humidity or water immersion, complete removal of salts and other water soluble materials from the metal surface is required; for maximum salt spray resistance, it is important to use a chromic acid rinse, leaving the metal in slightly acid condition.

### Preparing Structural Steel

The most pertinent characteristic of structural steel is the presence of hot rolling scale. The scale is comparatively brittle and will crack and flake under stress, particularly if heavy. Rust tends to form at crevices and spread between the scale and the metal.

The best treatment for scale is to remove it entirely by pickling or blasting, followed immediately by chemical treatment, or a coat of primer. Scale removal is not widely practiced owing to cost and production difficulties. It is, however, in use in some cases where particularly severe corrosion conditions must be met. If not removed completely mill scale is better not removed at all. Loose scale, of course, must be removed in any case. The worst possible way to remove scale is first to loosen it by weathering. Unfortunately, this method is rather widely practiced.

Hot phosphate treatments are excellent for structural steel, but the process can be used only prior to erection of a structure. Phosphoric acid cleaners are used successfully for cleaning ship hulls, storage tanks and other relatively smooth surfaces. If used for structural framework containing joints, crevices, etc., in which the acid can collect, excess phosphoric acid must be removed from crevices or from under loose edges of scale. If not removed, the resulting damage to the paint film will more than offset the value of the treatment.

### How to Prepare Zinc

Paint adheres poorly to new zinc, possibly due both to the extremely smooth surface and to chemical reaction between the metal and the paint. This is sometimes called "alkaline peeling," on the theory that the metal hydroxide formed in the presence of water reacts with paint acids. It has been proved that reaction occurs between the metal and paint vehicle decomposition products.<sup>2</sup>

It is not solely the burden of chemical treatments of the metal to prevent this reaction. The use of alkaline pigments and zinc dust in primers is well established. Reaction with paint decomposition products is thus distributed through the paint film rather than being concentrated at the metal-paint interface, where greatest damage to paint adhesion will result.

Weathering, mechanical roughening, and simple etching of zinc surfaces improves paint adhesion, but contributes no protection against corrosion. The best chemical treatment for zinc and galvanized iron



surfaces is the phosphate treatment as recommended for steel. Phosphoric acid cleaners are also used; these remove existing corrosion, improve paint adhesion, and give some corrosion protection.

Chromate and dichromate treatments as a class produce a passive surface as indicated by salt spray tests, but usually fall down on long exterior exposure tests. This may be due to the solubility of the coating, or inability of the coating to prevent reaction between paint and metal. These coatings consist of zinc oxide, zinc chromate and some may contain chromium oxides or hydrates. Passivation has been claimed due to slow release of hexavalent chromium to water. Zinc-coated sheet steel is marketed under various trade names, with surfaces chemically treated, usually with a phosphate treatment, to provide a better paint base. In painting over these metals usually excellent exposure results are obtained.

### Preparation of Aluminum

Due to the formation of a protective impervious oxide, aluminum is naturally resistant to corrosion. Pure aluminum is soft, and for many uses must be alloyed with small amounts of other elements, chiefly copper, manganese, silicon, and zinc. Much of the need for chemical treatment arises from the corrosive influence of the alloying metals. However, except for exposure to salt water, aluminum presents no great painting problem. Three types of simple chemical treatment are used prior to painting:

**Alkaline dichromate treatment:** The metal is alkaline cleaned, then immersed in dilute sodium carbon-

ate-sodium dichromate solution at near boiling temperature. The coating is then sealed by immersion in hot dilute dichromate solution.

**Chromic acid treatment:** The metal is cleaned, then immersed in dilute chromic acid at 120-140° F.

**Phosphoric acid:** This is usually phosphoric acid in solvents such as alcohols, applied by dipping or by swabbing.

The alkaline dichromate method produces the heaviest and best coating of these simple chemical treatments. These treatments are not suitable as protective coatings alone, but provide excellent surfaces for painting.

Anodizing, on the other hand, produces a coating which has considerable corrosion resistance without painting. The metal is alkaline cleaned, then immersed 30 minutes in dilute sulfuric or chromic acid. The metal is made the anode and the tank the cathode. Voltage, current density, temperature, and the solution are regulated to produce the desired coating. The film, essentially  $Al_2O_3$ , is initially porous, but is sealed by boiling 30 minutes in water or dichromate solution, converting the oxide to a hydrate.

Anodic coatings have considerable corrosion resistance. They are good surfaces for painting but need not be painted except when unusual protection is necessary. If the coating becomes soiled, the use of strong acid or alkaline cleaners before painting will damage the film. Anodizing is relatively costly, thus should not be considered as a quick metal preparation for painting, but rather as a high-quality coating for superior corrosion resistance, especially for resistance to salt water.



Normal atmospheres have little effect on magnesium other than discoloration. In salt water, the protective oxide coating is penetrated by the chloride ion, and corrosion is more rapid. The corrosion product is bulky, unsightly, and non-adherent. Paint applied to magnesium is subject to "alkaline peeling," similar to that experienced with zinc.

Most magnesium products are finished with a protective chemical coating even before final fabrication of the product. This coating is intended to protect the metal during storage, shipment and manufacture. The chrome pickle process, known as Dow No. 1 or AMC "A," is used for this purpose. The treatment comprises a short immersion in a solution of nitric acid and sodium dichromate. The coating is suitable as

a paint base, but cannot be used where close tolerances are required, due to etching of the metal. The dichromate process, known as Dow No. 7 or AMC "G," is the best process for corrosion resistance and is the most widely used as a base for painting. The process is as follows:

- (1) Solvent, vapor, or emulsion cleaning
- (2) Alkaline cleaning
- (3) Immerse in HF solution (10-25 percent)
- (4) Cold water rinse
- (5) Immerse 45 minutes in dilute sodium dichromate
- (6) Rinse cold and hot.

Magnesium can also be anodized, producing a coating which has excellent corrosion resistance. Probably the best known method is the Navy PT-13d Process.

### Conclusion

The following points are noted in conclusion:

(1) Metals should be cleaned thoroughly to remove soils and corrosion products before painting.

(2) Requirements for a good chemical coating as a base for paints are: Insolubility, adherence to metal, and ability to prevent reaction between paint and metal.

(3) Careful rinsing after any chemical treatment is essential for

maximum moisture and humidity resistance.

(4) Painting should be done as soon as possible after surface preparation.

(5) Simple chemical treatments are not of adequate protective value in themselves, but used as a step in a coordinated finishing program are of utmost value in extending paint life.

### References

1. Pollard and Porter, National Bureau of Standards Report, BMS-44, 1940.
2. H. J. Wing, Ind. & Eng. Chem. **28**, 242, 1946.

## All Records Expected To Be Broken During NACE Conference, Exhibit

**DEFEAT CORROSION**—That is the theme of the NACE Conference and Exhibition at the Palmer House in Chicago, April 7-10. During the four-day period, new and improved mechanical and electrical equipment and devices, and materials and services used to combat corrosion, and methods for their selection and maintenance will be disclosed and discussed. Thirty-five technical papers pertaining to industrial corrosion problems are scheduled during the eight symposia on the program.

**A**LL RECORDS are expected to be broken during the Third Annual All-Corrosion Conference and Exhibition of the National Association of Corrosion Engineers, scheduled April 7-10, 1947, at the Palmer House, Chicago. This prediction is based upon the fact that a pre-Conference poll conducted from the headquarters of NACE indicated approximately 75 percent of the membership would be in attendance, and the fact that the American Coordinating Committee on Corrosion will hold their meeting in conjunction with the NACE Conference.

More marked than in former years was the intense interest manifest by those persons concerned with corrosion problems. There was a pre-Conference feeling of unspoken determination to get the most out of



the eight technical sessions and the exhibit. Steadily mounting costs and material scarcities have created much concern among industrial heads, and they, more than ever before, are looking for ways and means to reduce the toll levied by corrosion on their plants, structures, and product.

New materials, alloys, equipments and devices are continually being searched out and developed to combat the destroyer—corrosion. The achievements both from a practical as well as a technical standpoint

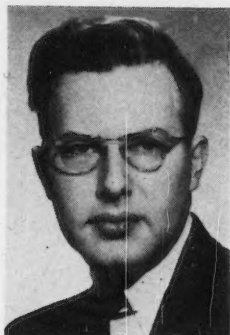
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G. P. Loschiavo



J. M. Bialosky



F. N. Alquist

will be revealed during the eight symposia and exhibition.

Among the speakers who present papers during the first of the technical sessions, the Water Industry Symposium, are Messrs. G. P. Loschiavo and J. M. Bialosky.

Mr. Loschiavo's paper pertains to "Treatment of Water in Army Supplies in New England." He gained knowledge of the subject through practical and theoretical experience gleaned during 1944-46, when he was assigned by the War Department to handle scale and corrosion studies in the New England area. Mr. Loschiavo is at present a chemical engineer with the headquarters of the Strategic Air Command, Washington, D. C., in charge of boiler treatment. Prior to the war, he was associated with the Byers Company as a ferrous and alloy chemist, specializing in water and fuel problems. He graduated from the University of Pittsburgh, majoring in chemistry and mathematics.

Mr. Bialosky, an associate metallurgist at the Armour Research Foundation, Chicago, speaks on "Cathodic Protection of Hot Water Tanks." His paper develops the

mechanism of the polarization which occurs in a freely corroding galvanic couple, describes the cathodic polarization resulting from the application of an external anode; the variability of water analysis and the factors which influence corrosion in hot water, and their effects on the application of cathodic protection.

Mr. Bialosky draws upon practical and theoretical knowledge obtained through the years since graduating with a B. S. degree in chemical engineering from the Case School of Applied Science. His experiences include research and development in the fields of welding fluxes, copper-clad steels, galvanized steel tanks for hot water tanks, protective coatings for steel containers, and various electroplating and electrochemical problems. He is the author of several papers on testing of protective coatings, metal cleaning, and galvanized hot water tanks, one of which, "Corrosion of Galvanized Hot Water Tanks," appears in this edition of Corrosion.

During the Chemical Industry Symposium, two of the four interesting papers programmed are "Fer-



V. J. Albano



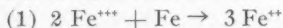
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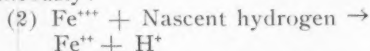
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ric Ion Corrosion During Acid Cleaning," prepared by Messrs. F. N. Alquist, J. L. Wasco and H. A. Robinson and to be presented by Dr. Alquist; and "Plastics for Corrosion Control," by Dr. J. W. Shackleton.

The paper to be presented by Dr. Alquist, who, like his collaborators, is associated with the Dow Chemical Company, Midland, Michigan, pertains to acid cleaning of heat exchange equipment, and points out that in the removal of iron oxide coatings with inhibited hydrochloric acid, the ferric ions react with the metal to form ferrous ion:



A second reaction takes place simultaneously:



Included are reports on laboratory studies of hydrogen evolution and corrosion rates in acid solution containing iron oxides and metal with various inhibitors.

Dr. Alquist has been associated with corrosion problems since receiving his A. B. in chemistry from Clark University in 1922, after leaving the army at the end of World

War I. From 1922-24, he was an instructor in chemistry at Rensselaer Polytechnic Institute, leaving there to join the faculty of St. Lawrence University. In 1925 he entered the University of Chicago graduate school, and left in 1926 to become an instructor in chemistry at Purdue University. He received his Ph.D. in 1930, and since has been associated with Dow Chemical Company, Organic Research Division. His work there includes research in phenols, chlorinated phenols, and organic nitrogen compounds. He has also done considerable work on metal corrosion inhibitors, corrosion problems, water type deposits and oil field chemical problems.

Dr. Shackleton, who is active in the Technical Service Department of the E. I. duPont DeNemours Company, Arlington, New Jersey, reveals a diversified background in the plastics field in his paper.

Dr. Shackleton, who holds the A.B. and M.S. degrees from Vanderbilt University, received his Ph. D. from the University of Illinois in 1941. He joined the duPont Plastics Department that same year as a re-





C. J. Couy



Faye O. Green



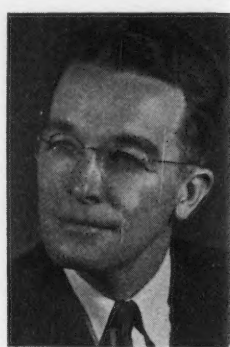
I. S. Dietze

search chemist, and later was assigned to the plant for development of lucite acrylic resin for wartime use by the aircraft industry. He subsequently served as a technical representative to the aircraft industry, and most recently has managed the sales development of polythene, and acted as technical service representative to the wire and cable industry.

Mr. V. J. Albano presents a comprehensive paper on "Electrochemical Factors in Underground Corrosion of Lead Cable Sheath," during the Chemical Industry session. The paper considers those forms of lead cable corrosion which are not attributed to the action of stray currents; and discusses the more common chemical or physical inhomogeneities in the metal, or in the environment, which set up minute galvanic cells, the operation of which cause electrical currents responsible for corrosion. The paper also considers the chemical constituents in the soil or in the underground cable plant in terms of their effects on the electrochemical behavior of these corrosion cells. Mr. Albano has a wealth of practical and technical experience

upon which he bases his contentions and findings. He is presently a member of the Technical Staff of the Bell Telephone Laboratories, engaged in electrochemical studies, particularly those concerned with corrosion of metals in soils and waters. He graduated from Cooper Union in 1930 with a B.S. degree in chemical engineering. He did graduate work at the Polytechnic Institute in Brooklyn, and undertook as his thesis a study of the "Rate of Solution of Zinc and Aluminum while Cathodic." He received his M.S. in chemistry in 1937.

Preceding Mr. Albano, James M. Standing, of the American Bell Telephone Company, will present a paper, "Potential Change Produced at Points Along a Uniform Underground Structure by Drainage Currents at Regular Spacings," which brings out that forced drainage, if applied at intervals along a structure, either by means of galvanic anodes or by means of power operated devices, permits assumptions to be made as to the uniformity of the structure, the spacing of the drainage points and the drainage cur-

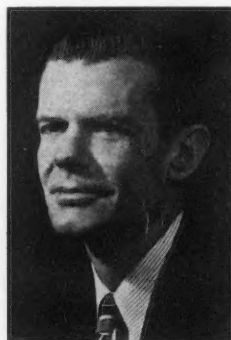
**W. E. Huddleston****R. M. Buffington****C. K. Ellert**

rent, and it is possible to develop approximate expressions for the change in potential to earth of the structure at points within the drainage system. These formulae are described in the paper. Engaged in work on lightning protection and cable corrosion problems since 1943 with American Telephone and Telegraph, he had previously been associated with Bell Telephone of Pennsylvania, for whom he did similar work, following his graduation from Haverford College in Pennsylvania with a B.S. degree.

Mr. C. J. Couy, Division Engineer

in the Distribution Department of the Duquesne Light Company, Philadelphia, presents the paper, "The Effects of Atmospheric Corrosion on the Economics and Maintenance of Guy Strand and Line Hardware," during the Electrical Industry session. This is the first part of a study of the deterioration with age of materials used in overhead line construction, with a view to the development of proper maintenance replacements, standards and programs.

Mr. Couy, a graduate electrical engineer, has been engaged primarily in the design, maintenance and operation

**D. B. Good****J. G. Kerley**

of electric transmission and distribution plants. His work gives him ample opportunity to study and observe the performance of materials used in construction.

Mr. I. S. Dietze, chairman of the Program Committee of the West Coast Regional Division of NACE, will present a paper explaining how cathodic protection was adopted to protect from corrosion due to high ground water and stray railway currents the lead sheaths of six single conductor 138 KV. cables, and six other 34.5 KV. cables which parallel and cross each other. Mr. Dietze, a native-born Californian, joined the Los Angeles Department of Water and Power in the Underground Section of the Design Construction Division after leaving the University of California, and is just now completing his 22nd year with the Department. During the past 18 years, he has been actively engaged in conducting electrolysis surveys on underground cables of the power system.

Dr. C. Kenneth Eilerts, senior physical chemist, and Faye O. Greene, of the Petroleum Experimental Station, Bureau of Mines, Bartlesville, Okla., are co-authors of the paper, "Alloying Steels for Corrosion Resistance to Gas Condensate Fluids," scheduled during the Gas Industry Symposium.

Papers scheduled during the final days' sessions, the General Industry and Cathodic Protection Symposia include "Non-Destructive Methods for Determining Metal Plate Thickness," by Mr. J. G. Kerley; and "Thermogalvanic Corrosion," prepared by Dr. R. M. Buffington. The latter's paper is a continuation of the one presented by Dr. N. E. Berry at the Kansas City meeting of NACE and published in the November, 1946, Corrosion. Dr.

Buffington's paper briefly defines thermogalvanic corrosion, and explains the basic principles from a thermodynamic point of view. Dr. Buffington, in abstracting his paper, writes, "It is shown by a simple test that irreversible processes which occur in the temperature gradient have no effect on the equilibrium potentials of two thermogalvanic cells, and it is predicted that this will prove to be quite generally true. This statement has far-reaching implications which emphasize the importance of thermogalvanic measurements in the study of the thermodynamics of electrolytic solutions, and has immediate application in the calculation of thermogalvanic potentials from entropy data. It quantitatively identifies the entropy change calculated from thermogalvanic data by means of the Gibbs-Helmholtz equation, with the entropy change of the electrode reaction. Theoretical values of thermogalvanic potentials are calculated approximately for a number of cells. It is shown that the dilution increases the tendency for metal to migrate from the hot to the cold electrode, thus either increasing or decreasing the potential, according to its sign. Factors which affect thermogalvanic corrosion rates are considered, and general conclusions drawn concerning the conditions which determine whether thermogalvanic corrosion can or cannot be important."

The seventh edition of American Men of Science has this to say about Dr. Buffington. "... Physical chemistry. Ness City, Kansas, Dec. 20, 96. A.B., Kansas, 18, AM., 21, Ph.D., California, 23. Nat. research fellow and research Assoc. Chem. California, 24-24. Instr., 25-26; research chemist,

Frigidaire Corp., Dayton, 26-23; research chemist and engineer, Servel, Inc., Evansville 33. Chem. Physical Soc.; Soc. Refrig. Eng.; Refrigeration; liquefaction of hydrogen; coefficients of thermal expansion of solids at low temperatures; hydrogen thermometry; entropy of aqueous ions; gas-solid reactions; heat transfer; refrigeration cycles; properties of refrigerants; dischlorodifluoromethane; air conditioning."

Mr. Kerley, who was reared and educated in Mississippi and received his B.S. degree in Electrical Engineering from Mississippi State in 1931, has prepared a paper outlining the six basic phenomena and methods employed in instruments for determining metal thickness non-destructively. The paper discusses the design, method of use, accuracy and limitations of an outstanding instrument in each field. The salient features of each instrument are tabulated in the conclusion, and a bibliography appended.

Mr. Wm. E. Huddleston's article, "The Determination of Pipe Protection by the Continuous Polarity Method," which will be presented during the Cathodic Protection Symposium, follows that the concept of determining the state of protection of a pipeline operating under cathodic protection is based on the theory that all points on a metal surface must be maintained definitely negative in polarity with respect to surrounding soil if full protection against external electrolytic corrosion is to be attained; any measurable discontinuity of pipe surface polarity is accompanied by discharge of protective current from the pipe surface, and is indicative of ineffec-

tual protection on the part of the cathodic protective system; and outlines procedures for locating and removing troublesome anodic points that can not be suppressed by means of cathodic protection.

After receiving his degree in electrical engineering from the University of Nebraska in his home state in 1930, Mr. Huddleston joined the Empire Pipeline Company. He was engaged in pipeline and pump station work for that company until 1935, when he undertook the study of pipeline corrosion problems, and served in the capacity of electrical engineer and corrosion technician for the Cities Service interests until 1946, when he launched himself as a consulting engineer, specializing in the prevention of external pipeline corrosion.

D. B. Good, of the Texas Pipe Line Company, drew up the paper, "The Location and Selection of Anode Systems for Cathodic Protection Units," which explains the procedure of various methods used for determining the location of anode systems for cathodic units, either by sight,—depending upon experience—or by determining the average soil resistivity in areas where cathodic units are contemplated. Curves reveal the relative efficiency of various anode configurations, variations of resistance with anode length for horizontal grounds, variation of resistance with buried depth and others. His paper also indicates the procedure for selecting the economical amount of anode, and the size of the rectifier to order if it is desired to order ahead of actual anode installation.

## Corrosion Abstracts

**Wrought Iron Plates for Smoke-Pipe Systems.** Marine Eng. & Shipping Rev., **51**, No. 5, 134 (1946) May.

Causes of corrosion of smoke-pipe systems on ships are explained. Wrought iron plates have been long recognized for their lasting qualities and usefulness in resisting corrosion in this application. Either welded or riveted for inner stacks, complete funnels, breeching, stiffeners or uptakes of wrought iron are used. Engineering information available from A. M. Byers Co.

**Heat and Corrosion-Resistant High Temperature Alloys.** Reference Book Sheet. Product Eng., **17**, No. 9, 151+ (1946) Sept.

Condensed and tabulated results of tests conducted by Allegheny Ludlum Laboratories and data from University of Michigan, Battelle Memorial Institute and General Electric and Westinghouse Laboratories on Alloy S-588 (nickel 19.21 percent, chromium 13.50-18.50 percent, Alloy S-590 (nickel 19.42 percent, chromium 20.88 percent, cobalt 19.31 percent, and Alloy S-816 (nickel 20.17 percent, chromium 19.84 percent, cobalt 42.28 percent). Includes chemical analysis, coefficients of expansion, strength at room and high temperatures, rupture tests

(graphed), creep rates, hardness results from various aging treatments, structure, recommended heat treatment and machining directions.

**Corrosion of Metals—IV. Corrosion of Iron and Steel.** Sheet Metal Inds., **23**, No. 231, 1333-1342+ (1946) July.

Among problems dealt with are the effects of coupling steel with other metals, intergranular, and corrosion-fatigue properties of stainless and heat resisting alloys. Methods for overcoming intercrystalline attack in stainless are enumerated, and the effect of copper on corrosion properties are discussed. The mechanism of corrosion and attack from air, sea water, and by pitting, as well as the effect of passivity are covered. Tables and graphs include: effect of hydrogen-sulfide on steels (mild, 8-17.3 percent chromium, 0.25 percent nickel, scaling of 50-33, 80-20, 63-15, 22-16, 35-15 percent nickel) chromium heat-resisting alloys, corrosion of stainless steels in copper sulphate-sulfuric acid mixture, results of atmospheric corrosion tests of wrought iron, carbon steel, 0.15 percent copper steel and 11.73-13.4 percent chromium steel, corrosion of copper-alloy steel in distilled water,

and corrosion of steels with and without copper in industrial, rural and marine atmospheres after 41, 132 and 162 months. 21 references.

**Corrosion Tests of Multi-Arc Welded High-Strength Aluminum Alloys.** L. W. SMITH, Cornell Aeronautical Lab. Paper before Electrochem Soc. 89th Gen. Mtg., Birmingham, Apr. 1946; Electrochem. Soc., Preprint 89-28 (1946).

Investigations on the corrosion resistance of welded aluminum alloys Alclad 24S and Alclad 75S are reported. Comparisons of bare and clad welded high-strength aluminum alloys by accelerated laboratory corrosion tests indicate the protective value of the cladding. Stress-corrosion cracking experiments on welded Alclad 75S-T alloys show freedom from susceptibility. Alclad 75S-T weld specimens in the reheat treated condition show stress-corrosion cracking in chromic acid, sodium chloride dichromate solution but not in boiling 6 percent sodium chloride. Field service correlation is necessary for final evaluations. Numerous illustrations and 17 references.

#### FUNDAMENTALS

**Isolation of the Protective Film on Passive Iron.** C. W. GIBBY AND D. DICKINSON, *Chem. & Ind.*, **1946**, No. 24, 227-228, June 15.

Isolation of the oxide film from iron wire was achieved by dissolving the wire anodically, and the film was then examined microscopically. Passivation had been carried out in potassium chromate solution. Films were found to consist of the original passive film, strong enough to preserve the original shape of the wire, and of secondary matter, which does not add to this strength. Experi-

ments proved definitely that the outer layers of the wire were more resistant than the interior at all stages of the electrolysis and, therefore both before and after formation of the secondary matter. Micrographs and diagram showing film and dissolution of wire.

**An Accurate X-Ray Investigation of the Oxides of Iron, Cobalt and Nickel—I.** V. I. ARKHAROV AND K. M. GRAEVSKY, *Zhur. Tekhn. Fiziki*, **14**, No. 3, 132-145 (1944) (In Russian); *J. Inst. of Met. & Metall. Abs.*, **13**, 165 (1946) May.

The lattice constant of ferrous oxide decreases as the distance increases from the pure metal to the outside surface of the oxide. In the case of nickel oxide and cobalt oxide on the other hand, the lattice constant increases towards the outside. The causes of slower oxidation of cobalt and nickel, as compared with iron, and the causes of the higher speed of oxidation of cobalt as compared with nickel are discussed.

**Effect of Electrolytic Deposits of Chromium and Nickel on the Oxidation of Iron at High Temperatures.** V. I. ARKHAROV, G. I. KOTUKHOVA AND E. I. REDKINA, *Zhur. Tekhn. Fiziki*, **10**, No. 14, 1210-1216 (1940) (In Russian); *J. Inst. of Met. & Metall. Abs.*, **13**, 170-171 (1946) May.

Thin deposits of chromium and nickel on iron increase its oxidizability at high temperatures. The protective action begins at a certain minimum thickness of the deposit, which depends on the temperature and length of time of exposure. Increased oxidation is connected with the predominance of ferrous oxide in the scale, while decreased oxidation



is characterized by the predominance of ferrosferric oxide and in part of ferric oxide in the scale.

**On the Mechanism of the Corrosion of Magnesium Alloys.** V. O. KRENIG, *Korroziya i Bor'ba s Ney*, 7, 3-11 (1941) (In Russian); *J. Inst. of Metals & Metall. Abs.*, **13**, 210 (1946) June.

Solid solutions high in aluminum and the compound magnesium aluminate are phases having a small hydrogen over-voltage among alloys of the magnesium aluminum system. Addition of manganese to magnesium aluminum alloys increases the hydrogen over-voltage of the solid solution and the intermetallic compounds and raises the corrosion-resistance of the alloy. Zinc dissolved in magnesium also increases the corrosion-resistance of the alloy by raising the hydrogen over-voltage. Magnesium silicide compound causes intensive corrosion.

**Hydrogen Overvoltage as a Factor in the Corrosion of Metallic Couples.** L. F. LE BROcq AND H. C. COCKS, *Nature*, **156**, 536 (1945); discussion by T. P. Hoar, **157**, 408-409 (1946)

Frequent neglect of the influence of hydrogen over-voltage on the corrosion current between metallic couples in electrolytes is pointed out. Current should only flow when the potential difference on open circuit is greater than the hydrogen over-voltage at the cathode, and depends on the difference between these quantities. Experiments on a magnesium alloy and copper in sea-water confirm this. The considerable corrosion current is greatly reduced by amalgamation of the copper with

mercury which has a high over-voltage. The discussion by Hoar is graphically illustrated.

**An Electron Diffraction Study of Oxide Films Formed on Iron, Cobalt, Nickel, Chromium and Copper at High Temperature — TP2068.** E. A. GULBRANSEN AND J. W. HICKMAN, Westinghouse Electric Corp. Paper before AIME, Atlantic City, Nov., 1946; *Metals Tech.*, **13**, No. 7, 1-26 (1946) Oct.

Review of literature on electron diffraction study of iron, cobalt, nickel, chromium and copper. The following was studied: (1) vacuum-formed films at elevated temperatures; (2) effect of surface preparation; (3) low-temperature oxidation of iron; (4) high-temperature oxidation of iron; (5) effect of cooling atmosphere on oxides observed at room temperature; (6) the effect of heating and cooling films of known thickness. The oxidation of cobalt indicates one lattice transformation between  $\text{Co}_3\text{O}_4$  and  $\text{CoO}$  at  $400^\circ$  to  $600^\circ\text{C}$ . No lattice transitions occur in oxides formed on nickel chromium and copper. Crystal growth and orientation effects are noticed indicating physical changes in the face oxides of thin metals. Tables and drawings. 23 references.

**Overvoltage of Hydrogen in Relation to the Composition of the Electrode Material.** V. CROATTO AND M. DA VIA, *U. Croatto. gazz. chem. ital.*, **73**, 117-143 (1943); *Monthly Rev., Am. Electroplaters' Soc.*, **33**, No. 8, 848 (1946) Aug.

The overvoltage of hydrogen in 6 normal potassium-hydroxide was studied with lead-tin and lead-cadmium alloy cathodes of varying com-

position. The current density required to attain a given overvoltage depends linearly on the alloys composition in the eutectic region, but not in the regions of solid solutions, due to the different number of active centers on the surface. In 15 normal sulfuric acid at 120° C., lead containing small amounts of silver nickel or copper corrodes electrochemically because of the occurrence of two separate phases; with small amounts of zinc, tin, antimony, cadmium or bismuth, corrosion is "purely chemical" (displacement of hydrogen).

#### GAS AND CONDENSATE CORROSION

**Prevention of Condensate Well Corrosion by Chemical Treatment in the Erath Field.** W. D. YALE, The Texas Co., Corrosion, 2, No. 2; 85-94 (1946) June.

Corrosion by acid attack (caused probably by dissolved carbon dioxide or organic acids or a combination) in Southern Louisiana condensate well field tubing was investigated by internal tubing caliper survey, water analysis and coupon exposure tests. Coupons were of SAE 1020 steel. It was found that sodium dichromate is an effective corrosion inhibitor, and after its use there was no evident corrosion over a period of seven months. Coupon tests showed a reduction in corrosion rates from 88 to 96 percent. The possibility of reducing corrosion rates and localized pitting by substituting internally flush, fully normalized 10.2-pound J-55 tubing for 8-round upset N-80 tubing is being investigated, but no conclusive data have yet been obtained. Stainless steel, bronze-lined and weld-lined

valves are also being tested. The work was carried on a purely practical basis as a protective measure only. It will be continued in cooperation with the NGAA, NACE and API committees.

#### GENERAL CORROSION

**Corrosion-Resistant Alloys.** Steel, 119, No. 5, 70-75+ (1946) July 29.

Hastelloy A, B, C and D find wide use in industries handling reactive acids. Range of use, fabrication and welding procedures, mechanical properties and tables giving results of penetration tests in hydrochloric, sulfuric, nitric, phosphoric, formic and acetic acids are discussed and shown. Parts are illustrated.

**Corrosion of Metals.** Report before Inst. of Physics, Nature, 156, 435-438 (1945); J. Inst. of Met. & Metall. Abs., 13, 168 (1946) May.

Among the topics discussed are the hydrogen-evolution and oxygen-absorption types of corrosion, and the influence of anodic polarization on the latter; atmospheric corrosion; the reaction between copper and oxygen and the periodicity of oxygen absorption by strained copper; corrosion of steel in air and liquid media; the use of paints and metallic coatings to combat corrosion; the design of electrochemical apparatus for corrosion studies; and, finally, corrosion in telecommunication plant and measures available for reducing it.

**Broad Research Program Enlists Aid of Private Facilities.** Steel, 118, No. 19, 70-73 (1946) May 13.

The new Navy multi-million dollar research program, which draws university and industrial laboratories into the picture on a contract

basis and results of which will be freely publicized, is described. The University of Illinois will be developing better criteria for selecting steels. Carnegie Institute of Technology will be dealing with the kinetics of reaction in steelmaking. Battelle will conduct fundamental research on heat resistant materials. The Naval Research Laboratory has been assigned a project on contact alloys. The latter laboratory and Ohio State University are involved in a fundamental corrosion study, to seek more information about corrosion in general, corrosion fatigue, erosion and corrosion in combination.

**Corrosion Resistance of Aluminum and Its Alloys.** R. B. SPACHT, National Bronze and Aluminum Foundry, J. Chem. Educ., **23**, No. 5, 253-257 (1946) May.

Chemical corrosion of aluminum is discussed and tabulated. Conditions leading to electrolytic corrosion are described. The table showing weight losses of aluminum discs when exposed to various atmospheres, includes aluminum-nickel. The effect of various metals when alloyed with aluminum is given. As to protective coatings, those such as nickel and chromium, which are cathodic to the aluminum base offer protection only until broken and then hasten its corrosion.

**Corrosion—Arch Enemy of Line Hardware.** B. J. BARMACK, Electric L. & P., **24**, 58-60 (1946) Aug.

Suggests several possible methods for prolonging the life of hardware used on electric lines. Poles and arms now have life expectancy of almost 30 years, but hardware

usually lasts only half that time.—BLR.

**Products of Corrosion—Iron Oxides, Hydrated Oxides, and Hydroxides.** RICHARD C. COREY, Combustion, **17**, 45-51 (1946) June.

Discusses those phases of corrosion research where systematic studies of the products of corrosion are most needed to provide a better understanding of the mechanism involved; also in so far as is known, the chemistry of the products formed by corrosion of iron and steel under some conditions met in power plant practice; and suggests the data that are needed to determine the essential properties of corrosion products.—BLR.

**Agents, Basic Causes, Control and Prevention of Corrosion.—I.** F. A. PRANGE, Phillips Petroleum Co., Oil & Gas J., **45**, No. 18, 88+ (1946) Sept. 7.

An elementary discussion of the types of corrosion, inhibitors and accelerators of corrosion and the effects of temperature, fluid flow, concentration, electro-chemical factors, oxygen concentration and acids.

**Learn the A-B-Cs of Corrosion if you would Get Longer Life from your Equipment.—II.** F. A. PRANGE, Oil & Gas J., **45**, 88-90, 92 (1946) Sept. 14.

Discusses and illustrates various types of corrosion and ways of preventing or minimizing it with particular reference to oil-field equipment.—BLR.

**Preserving Artillery Pieces.** W. H. WALTER, Steel, **119**, 100-102, (1946) Sept. 16.

Details low-cost procedures used in preparing heavy gun parts for long-term storage in welded steel containers.—BLR.

**Metallic Corrosion Passivity and Protection.** ULICK R. EVANS, Pub. by Longmans, Green and Co., New York. 836 pp. 1946.

Chapter headings are as follows: Simple examples of corrosion and passivity; study of thin films; oxidation at high temperatures; corrosion in moist or polluted atmospheres; corrosion not involving the absorption of oxygen; corrosion of ferrous materials involving the absorption of oxygen; corrosion of non-ferrous materials involving the absorption of oxygen; influence of stress, strain and structure; influence of contacts and crevices; protection by inhibitive treatment of water; protection by chemical and electrochemical treatment; protection by paints and enamels; protection by metallic coatings; and testing. Each chapter is divided into sections on theory, practical problems, and quantitative treatment. This exhaustive work includes extensive literature references.—BLR.

**Glossary of Terms Used in Corrosion.** Electrochem. Soc. Preprint 90-12: 8 pp. (1946) Oct. 21.

Definitions of corrosion terms prepared jointly by the Editorial Advisory Board of the Corrosion Handbook and Sub-committee V of the American Coordinating Committee on Corrosion are given.

**Corrosion Forum.** O. S. TRUE, FREDERICK L. HUNTER, H. C. ESGAR, D. F. SIDDALL, F. E. HERSTEIN AND

C. L. BULOW, Chem. Eng. **53**, 203-204 (1946) Aug.

Part II of a symposium designed to outline the usefulness of various representative materials in phosphoric acid service. Contains sections on rubber tantalum, stainless steel, vinyl-base paints, chemical stoneware, and copper and copper-base alloys. Last section includes tables on corrosive resistance of pure copper and a number of alloys.—BLR.

**How Inserts Can Be Used in Die Castings.** Die Casting, **4**, No. 6, 28-30+ (1946) June.

The die cast handle of a fishing pole contains a cast-in brass tubing insert with a blind hole to prevent galvanic corrosion between the steel rod and the zinc alloy handle.

**Changes of Metallic Surfaces Caused by Flowing Liquids.** M. VATER, Z. Metallkunde, **36**, No. 2, 38-43 (1944); J. Inst. of Met. & Metall. Abs., **13**, 212 (1946) June.

A study was made of the effects produced by cavitation and water impact on the polished surfaces, carbon and stainless steels, special brass and bronze, and silumin. The resulting surface colors are shown photographically, and their origin, nature, and relation to corrosion are discussed with reference to the results of other workers. It is concluded that the surface colors are caused by adsorption phenomena and that previous theories of local high-temperature formation in the area of water impact are without foundation.

#### INHIBITORS

**Zinc-Yellow—A Corrosion-Inhibitive Pigment.** W. F. SPENGEMAN AND

D. H. LAWSON, Paint, Oil and Chem. Rev., **108**, No. 20, 9-10+ (1945); Brit. Abs., **BII**, 130 (1946) Apr.

Zinc chromate, in combination with an alkyd medium, has proved of value as a corrosion-inhibitive pigment in primers for aluminum, magnesium and ferrous metals for marine use, etc.

**Corrosion of Iron by Water-in-Oil Emulsions.** L. C. VERMAN AND M. L. KHANNA, J. Sci. Ind. Res., India, **4**, 449-450 (1946); Brit. Abs., **BI**, 205 (1946) June.

Corrosion is inhibited by chromium soaps, which not only have a specific antioxidant effect but also reduces the rate of diffusion of water through oil layers.

**Anticorrosive Action of the Oxalic Acid Series.** S. S. BHATNAGAR AND K. G. KRISHNAMURTHI, J. Sci. Ind. Res., India, **4**, 238-240 (1945); Brit. Abs., **BI**, 181 (1946) May.

The attack of rapeseed oil (I) on brass at 150° is reduced by  $[\text{CH}_2] n^\circ \text{CO}_2\text{H}_2$  (II),  $n = 3 > n = 2 > n = 1 > \text{H}_2\text{C}_2\text{O}_2$  (III), being completely inhibited by 0.05 percent of succinic acid. Addition of 0.05 percent of ethyl oxalate or (III) but not of 0.1 percent of  $\alpha\text{-C}_{10}\text{H}_7\text{OH}$  (IV) almost completely inhibits corrosion of brass bearings by mineral oil—(I) or groundnut oil (V) blends after 30 days' running. (II) is ineffective, and (III) inferior to (IV), in inhibiting peroxidation in (V) at 100°, but (III) is superior to (IV) in delaying the drying of linseed oil films. The bearing of these results on the action of lubricants is indicated.

**Corrosion Inhibitor.** Chem. Eng., **53**, No. 8, 152 (1946) Aug.

Development of a new brass corrosion inhibitor has been announced by Dr. Johan Bjorksten, Industrial Research Chemist, 185 North Wabash Ave., Chicago 1, Ill. Under the trade name of Brass Lyfe, this material is now being manufactured on a commercial scale by the Bee Chemical Co., 63 East Lake St., Chicago, Ill. Consisting of a 10 percent solution of the active agent in butyl cellosolve it is effective only on copper and copper alloys. It is miscible with and may be added to oils, lubricants and lacquers and will stop various types of corrosion.

**Extract of Linseed Meal as an Inhibitor of Iron and Steel Corrosion.** E. I. GUROVICH, J. Applied Chem., USSR, **19**, No. 2, 140-147 (1946).

The action of inhibitors obtained from linseed meal has been investigated. This action seems to be induced by the adsorption of colloidal particles of albuminous substances by the surface of the treated metal, thus decreasing the rate of dissolution of such surfaces. The process of extraction of this inhibitor is described. Tests show that effectiveness of such inhibitors is equal to or higher than that of those in common use.—BLR.

**Layer Theory of Passivity. Theory of Inhibitors and Phosphatization.** W. MACHU, Korrosion u. Metallschutz, **19**, 140-146 (1943); Chem. Abs., **40**, 5323 (1946) Sept. 20.

Statements of R. Weiner and F. Halla that deny the validity of Müller's theory of passivity and its application to inhibitors and passivity

are contradicted on the basis of theoretical considerations and explanation findings. The author's theory of inhibitors and phosphatization was derived independently of Müller's layer theory of passivity.

**Amines and Corrosion Control.** G. CORSARO, *Nat. Eng.*, Feb., 1946; *Power Notes*, **33**, No. 3, 3-5 (1946) May-June.

Use of amines for return line corrosion control is discussed. The results of a few simple laboratory experiments with various kinds of boiler feedwater are reported. Corrosion troubles caused by condensates usually originate at the boiler feedwater.

### INSPECTION

**Supersonic Flaw Detector and Its Applications in the Sheet Metal Industries.** A. C. RANKIN, *Sheet Metal Inds.*, **23**, No. 229, 893-898 (1946) May.

After a general discussion of the field of testing to be covered, examples are given of the application of supersonic testing to ferrous and nonferrous metals. Stage for application of test is discussed and both direct transmission and reflection methods are covered. Its use in locating primary segregation, porosity and inclusions is described. Oscillograms on duralumin sheet are shown.

**Influence of Heat Treatment Upon the Susceptibility to Graphitization of High Aluminum Deoxidized Carbon-Niobium Steel.** F. EBERLE, *Welding J.*, **25**, 307s-312s (1946) May.

Describes a series of experiments carried out to explore the influence. BLR.

**Effect of Working on the Physical Properties of Molybdenum.** J. W. MARDEN AND D. M. WROUGHTON, *Westinghouse Temp. Co. Paper before Electrochem. Soc. 89th Gen. Mtg.*, Apr., 1946, Birmingham, *Electrochem Soc.*, Preprint **89-30** (1946).

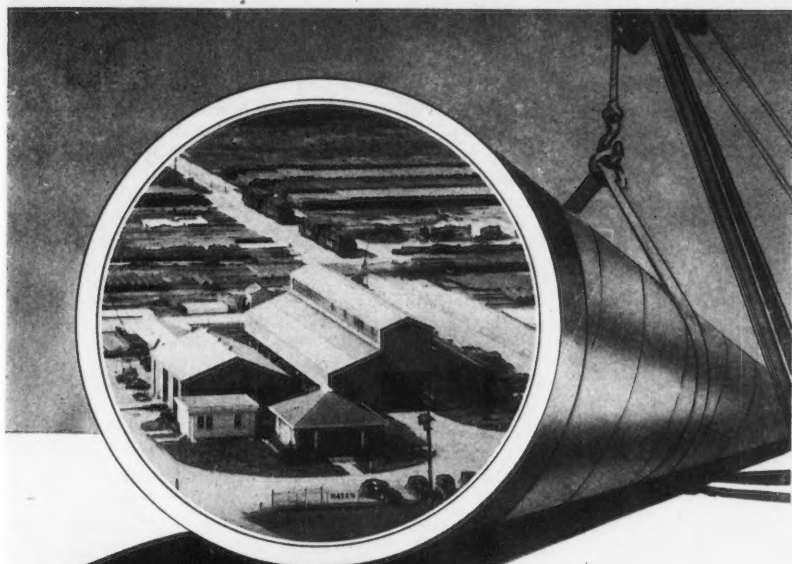
Numerical values are recorded for hardness, ultimate tensile strength and percent elongation of molybdenum wire and sheet having had various amounts of mechanical working. The data indicated only the range that may be expected and are not exact for any given piece of metal. It is indicated that the methods of working, annealing, etc., greatly affect the strength and ductility of the metal. No metal is inherently a moderately hard, very brittle metal and the properties of high strength and ductility found in commercial metal are properties imparted to it by mechanical treatment and heat-treatment. Graphs are shown.

### METAL FAILURE

**Lockwasher Breakage Resulting from Hydrogen Embrittlement.** W. L. FLEISCHMANN, *General Elec. Co., Product Eng.*, **17**, No. 7, 150-152 (1946) July.

Investigations of lockwasher breakage reveal that hydrogen embrittlement is a cause of failure. Breakage occurs oftener in plated parts. Typical failures of this type are photomicrographed; manufacturing processes, tests for hydrogen embrittlement, materials most commonly used, and avoidance of this defect are discussed. Material is chosen on the same basis as for springs: a steel with high ratio of yield strength to tensile strength





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plus sufficient ductility. 0.60 carbon steel is widely used. Heat treatment is described. Hydrogen diffusion during plating is so much more rapid from thin than thick sheet that thin lockwashers seldom fail from this cause.

**Corrosion of Metals—IV. Corrosion of Iron and Steel.** Sheet Metal Ind., **23**, 1333-1342 (1946) July.

Deals with effects of coupling iron with other metals, intergranular attack of iron and its alloys, intergranular attack of improperly heat-treated stainless steel, corrosion-fatigue properties of various iron-alloys, corrosion of stainless steel.—BLR.

**Improvement of the Notch Impact Resistance of Gas-Welded Joints.** A.

MATTHEW AND H. KOCH, Autogene Metallbearbeitung, **35**, 93 (1942) Apr.; Welding J., **25**, No. 6, 359-s-360-s (1946) June (Abridged Transl.)

Because it was found more difficult to meet certain German specifications for impact values by gas welding than with coated electrodes, tests were undertaken to improve the impact values of gas welds. Base metal was boiler plate. Different effects from changing positions, from redesign of joints, and use of a low-alloy welding rod were studied, as well as the influence of peening at temperature of red heat, and the effect of decreasing overheating in horizontal welding by directing flame away from welding rod, and also limiting the amount of heat delivered to top side while welding the bottom side of joint by making an unsymmetrical joint. The influence of overheating on impact values is shown by the fine grain structure of the best specimen and the coarse

grain of the worst. It was finally concluded that the solution did not lie so much with technique as with proper selection of electrode. Composition of low-alloy rod used is not mentioned in abstract translation.

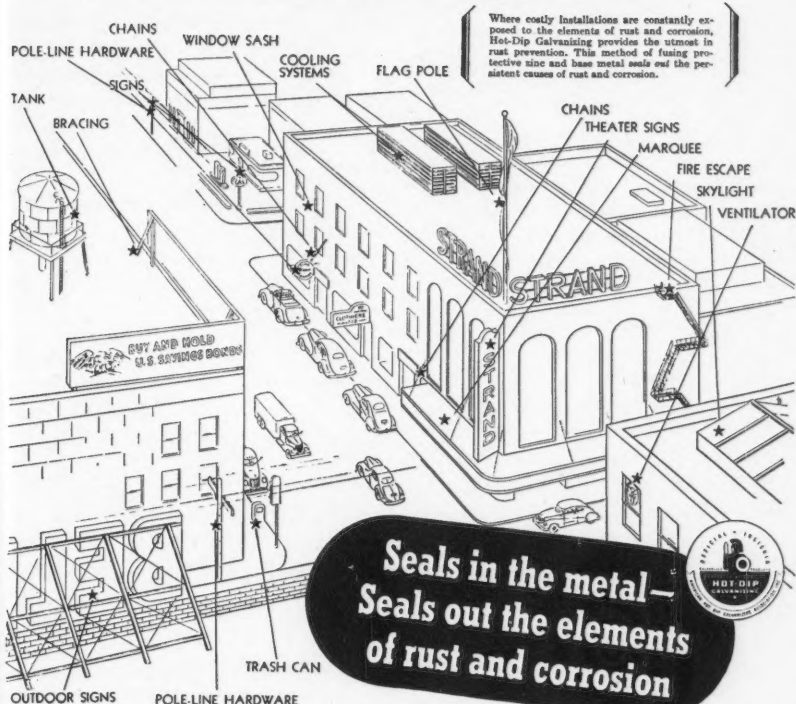
**Stress Corrosion with Steel Bottles for Compressed Gas.** H. DE

LEIRIE, J. COUTURE AND C. CRUSSARD, Metaux-Corrosion-Usure, Nov.-Dec., 1944; Metallurgia, **33**, No. 198, 326-27 (1946) Apr.

Corrosion failures of steel compressed-gas bottles, rarely intercrystalline in character, are reported. Heat-treated carbon steel bottles are more resistant than alloy steels (no alloy compositions mentioned). It is said that hardening addition elements contribute to failure by creating internal stresses. French technicians do not accept the German chemists' theory that hydrogen cyanide is the dominant aggressive agent. An article in J. des Usines a Gaz, Dec., 1945, recommends that because of the technical difficulties in increasing corrosion resistance of a metal under tensile stress, solution lies in purification of the gas or use of superficial protection of bottles. The problems of interior linings has not been entirely clarified. Statements of the French Commission Centrale des Appareils (pressure steam and gas) are quoted. Conclusion of authors is to use only ordinary steel for road vehicles operated on compressed town's gas, and to use light alloy containers if weight must be retained. Practically all failures have been in alloy steels to date. There have been none with light alloys. One failure was reported with banded steel and one with open-hearth Martin steel,

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**Metal-Clad Unit-Type Switchgear for 33-Kv Service.** C. H. KREGER, *Elect. Eng.* **65**, No. 6, 360-368 (1946) June.

Experience with metal-clad equipment is reported. The most serious problem arising was with corrosion in shell bushings, mounted over openings in bottom of metal boxes or gear housing and serving as sockets for oil circuit breakers. Caps and contacts at top of shell corroded. Lead gaskets were eliminated and surfaces were tinned, except for contact surfaces which were silvered. Plating surfaces with copper or chromium was not successful.

**Stress Corrosion in Light Alloys.** H. G. PETRI, G. SIEBEL AND H. VOSS-KUHLER, *Aluminum*, **26**, No. 1, 2-10 (1944) (Transl.); *Light Metal Age*, **3**, No. 11, 23-28+ (1945) Nov.

Effect on stress corrosion resistance of aluminum-magnesium-zinc alloys by the addition of cerium, titanium, copper, manganese, chromium, vanadium, iron, silicon increased magnesium-zinc content and other factors are studied.

**Cavitation—A Modern Metallurgical Problem.** F. T. SISCO, *Mining & Metall.*, **27**, No. 475, 402 (1946) July.

Brief summary of cavitation phenomena. Use of high nickel alloys, especially Monel, is recommended, especially if rotating part is designed so that formation of voids in the liquid can be held to a minimum.

**Effect of Supersonic Waves on Surface Reaction of Metals (Copper and Iron).** J. A. HEDVALL, *Tekn. Tidskr.*, **74**, 625-626 (1944); *J. Inst.*

*of Met. & Metall. Abs.*, **13**, 170 (1946) May.

Experiments are described in which the rate of formation of surface reaction products was studied when copper was exposed to iodine vapor or sulfur fumes, and iron to oxygen. An apparatus was used with which the specimens could be subjected to supersonic waves generated by a quartz oscillator. Curves show the marked increase in the reaction rate produced by supersonic waves.

**Corrosion on the Muothal-Iberg H. V. Transmission Line.** E. SCHILLING, *Bull. Assn. Suisse Elect.*, **36**, 741-744 (1945); *Elect. Eng. Abs.*, **49**, 12 (1946); *J. Inst. of Met. & Metall. Abs.*, **13**, 168 (1946) May.

Faults have often occurred on the bare conductor line over the Iberg, especially since the increase in operating voltage from 8 to 15 Kv. The conductor fractured because half of the cross-section of the Aldrey cable had suffered deterioration at the tension towers. The cause of the corrosion of the conductor was probably intense corona at defective insulators, which continued to give service as they were supported on wooden towers. Binding the cables at the supports with aluminum tape failed to reduce the damage appreciably; other remedies are necessary, such as overvoltage protection, strengthening of the insulators, supervision and replacement of defective insulators.

**Erosion (of Pump Impeller) Proved by Laboratory Test.** G. H. INGELS, *Cook Heat Treating Co., Southern Power & Ind.*, **64**, No. 6, 61-62 (1946); *Chem. Abs.*, **40**, 4334 (1946) Aug. 10.

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**Relation Between Welding and Corrosion of Stainless Steels.** A. DE SY, *Revue de la Soudure* (Belgium), **1**, No. 2, 3-26 (1942); *Trans. Inst. of Welding*, **9**, No. 2, 65 (1946) Apr.

Corrosion is examined with reference to stainless steels. Intergranular corrosion, pitting and stress corrosion are treated in detail. The techniques for welding martensitic chromium, ferritic chromium and austenitic chrome-nickel are given.

**Efficiency and Cavitation of Fluid Machines.** H. H. ANDERSON, *Inst. of Mech. Eng.* 1946, Adv. copy, 3 pp.; *Engineers' Digest*, Am. ed., **3**, No. 8, 411-413 (1946) Aug.

Efficiency and cavitation tests of a multi-stage single-entry type of hydraulic pump are reported. Reynold's Curve and Moody's formula are used. Methods of determining cavitation limits are described and a cavitation curve shows tests plotted against curve of suction.

**Some Stress-Corrosion Studies on Austenitic Cast Irons.** J. B. URBAN, J. W. BOLTON AND A. J. SMITH, *Lunkenheimer Co. Paper before ASME, Fall Mtg., Cincinnati, Oct., 1945* *Trans. ASME*, **68**, No. 6, 633-636 (1946) Aug.

Austenitic cast iron specimens

containing 19-20 percent nickel, 1.60-1.75 percent chromium, 0.62-0.90 percent molybdenum and 0.06-4.55 percent copper were immersed in 50 percent caustic solutions and boiled, using a reflux condenser, for periods up to 6 mos. and were then broken in impact test. Results were equal to those of samples not exposed showing that caustic embrittlement does not result when stress is absent. Creep tests showed the materials withstand stresses to 15,000 psi at 350° F. without measureable creep. A combined test was then carried out consisting of exposure to 50 percent commercial caustic at 280° F. while tensile, cantilever and beam loading was applied. Summary of test results is tabulated and graphs are shown. Gray cast iron sustained a tensile load of 25,000 psi for 284 hours and 10,000 psi for 2600 hours, while austenitic iron failed under a load of 20,000 psi after 0.7 hours on one specimen. At a stress of 10,000 psi, load was sustained for 2600 hours without fracture. Curves show there is a limiting stress below which the effects of stress corrosion on austenitic irons are either negligible or non-existent. Stress-strain curves are shown. The SR-4 resistance strain gage method is described in appendix.

**Steel-Tower Corrosion Presents a Problem.** C. M. LYTLE, *Elec. Light & Power*, **24**, No. 5, 58 (1946); *Chem. Abs.*, **40**, 6044 (1946) Oct. 20.

The tower is located near a power station. Joints and bolts were badly corroded by electrolysis brought about by changing currents. Measures taken to remedy the situation are described.





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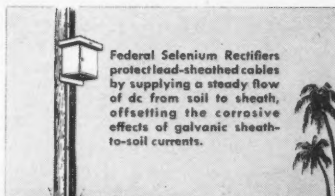
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**Cavitation Observation on Centrifugal Pumps.** R. DZIALLAS, V.D.I. *Zeitschrift*, **89**, No. 3/4 (1945) Jan. 20; *Engineers' Digest*, Am. ed., **3**, No. 8, 403-406 (1946) Aug.

Results of cavitation experiments with airfoil sections are reported, deductions for the occurrence of cavitation in impellers of centrifugal pumps, results of stroboscopic observations on impeller eye during constant speed tests, representation of area of cavitation danger, and conclusions for designing centrifugal pumps are given. For large pumps it is advisable to deposit stainless steel by welding onto cast-steel impellers most exposed to cavitation dangers.

#### REFINERY CORROSION

**Corrosion Limits Metals that Can Be Used for Construction of HF Alkylation Units.** Nat. Petr. News, **38**, No. 32, R-618+ (1946) Aug. 7.

To determine the corrosive effects of hydrofluoric acid on metals and which materials are most desirable for the construction of HF alkylation units, Phillips Petroleum Co. conducted a series of extensive pilot plant and laboratory tests. As a result, corrosion is not now considered a serious problem in HF alkylation, although there are still two unsolved metallurgical difficulties—the blistering of steel and the breakage of bolts, plugs, and other fittings. This article presents a summary of these tests on the corrosion of metals by hydrofluoric acid, and correlates the data with actual experience in commercial operations. Several metallurgical problems that have been encountered, including the two mentioned above, are also included.—GPC.

#### SURFACE TREATMENT

**Black Anodic Coatings on Aluminum Alloys.** ROBERT S. HERWIG. *Monthly Rev.*, **33**, 609-611 (1946) June.

Method consists in treating the aluminum anodically in a solution of 15 to 25 percent sulphuric acid for a period of 15 to 90 minutes at temperatures ranging from 67° to 88° F., and current densities of 2 to 18 amperes per square foot. Resulting anodic coating is immersed for 10 to 30 minutes in a black dye bath maintained at 120° to 140° F. and then sealed in either hot water or nickel acetate solution.—BLR.

**Phosphate Processes as a Pre-Treatment for Metal Finishing.** H. A. HOLDEN. *Sheet Metal Ind.*, **23**, 1539-1546 (1946) Aug.

Description of the basic operations involved in the phosphate treatment of metal surfaces prior to organic finishing. Discusses various applications.—BLR.

**Environmental Control of Metal Cleaning Processes.** F. A. PATTY. *Monthly Rev.*, **33**, 945-953 (1946) Sept.

Water cooled condensers vs. thermostats; solvents; trichloroethylene vs. tetrachloroethylene; stabilizers; heat source and heat controls; sludge removal; location of equipment; ventilation; common causes of solvent loss.—BLR.

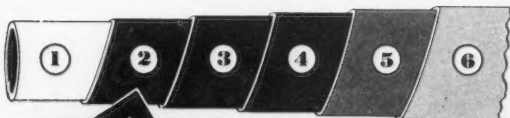
**Electrically - Heated Oxidizing Tank.** *Ind. Heating*, **13**, No. 8, 1343 (1946) Aug.

A new, electrically-heated oxidizing tank for heating D.C. Oxidizing Compound (product of D.C. Cooper Co.), a product for producing a deep,

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uniform, blue-black finish on steel parts that will not peel, rub off, crack or chip, is described and shown. A single bath produces a rust-resistant surface effect within 5 to 15 minutes without changing dimensions of treated parts.

#### **Advantages of Phosphating Iron.**

H. FORTMANN, Metallwaren-Ind. Galvanio-Tech., **41**, 329-330 (1943); Chem. Abs., **40**, 6036 (1946) Oct. 20.

In spite of the additional necessity of lacquering, phosphating represents an essential improvement in the treatment of steel both from the standpoint of resistance to corrosion and that of economy. Examples are reported illustrating the mechanical corrosion resistance of phosphated and lacquered bolts and sheet metal.

**Corrosion of Metals—III. Corrosion Testing "Electron."** Sheet Metal Inds., **23**, No. 229, 933-940+ (1946) May; **23**, No. 230, 1145-46+ (1946) June.

Problem of corrosion testing as a whole considered; the difficulties that arise, precautions that must be taken and importance of interpretation of results are indicated. Industrial tests are classified as: (1) routine testing to maintain a standard of quality; (2) comparison of different materials; (3) estimation of expected life of a metal in a given environment; (4) study of special properties of a metal or alloy, and (5) tests for developing new alloys. Extent of corrosion may be assessed by loss in weight, gain in weight, maximum depth of localized corrosion, measurement of hydrogen evolved, change of electrical resistance, electrical measurements of potential, loss in tensile strength, de-

crease in oxygen content of solution, and visual, microscopic, and microchemical examination.

**Corrosion of Inserts.** A. J. FERKO, Metal Ind., **68**, No. 24, 467-468 (1946) June 14.

Tests carried out by Boeing Aircraft Co. to determine galvanic corrosion of a magnesium casting alloy (containing 6.0 percent aluminum, 0.2 percent manganese, 3.0 percent zinc, caused by inserts of oilite bronze, No. 410 corrosion-resistant steel, manganese bronze, cadmium-plated and zinc-plated carbon steel, and carbon steel, respectively. Magnesium samples were given chrome-pickle and bichromate treatment, as well as no treatment. All showed galvanic corrosion after salt spray tests, but degree and location of corrosion differed. Results are tabulated and samples shown.

#### **WATER CORROSION**

##### **Water Treatment in Refineries.**

R. W. KELLY, Dearborn Chem. Co., Paper before Western Petrol. Refiners Assn., Regional Tech. Mtg., Lansing, Mich., June 20, 1946 Petr. Refiner, **25**, No. 8, 143-144 (1946) Aug.

Phases of water treatment pertaining to the oil refining industry are covered.

**Magnesium Protects Heaters from Corrosion.** Modern Metals, **2**, No. 7, 38 (1946) Aug.

Protection for special alloy hot water tanks eaten by acid-charged waters is afforded by insertion of a pure magnesium rod in tank. This forms a galvanic battery with the steel and magnesium goes into solution to protect the steel by a plat-

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ing action. The current is reduced by a resistance placed in series between the iron and magnesium rod. Field tests were very successful. Tank is shown with rod inserted.

**Corrosive Action of Water on Lead. Method of Determination of Lead in Water.** J. A. RAGGIO, Rev. admin. nac. aguas (Buenos Aires) **10**, 170-177 (1946); Chem. Abs., **40**, 4648 (1946) Aug. 20.

The investigation was performed by putting lead foil or plates 7.5 by 2.5 cm. in 200 ml. of water in a stoppered glass cylinder at 20°. The glass of the cylinder adsorbed some of the lead which thus escaped determination. This lead could be removed by washing the glass with 50 percent nitric acid or by adding citric acid or sodium citrate to the water under examination. The lead was determined colorimetrically with dithizone.

**Corrosion Control.** S. T. POWELL, Paper before AWWA, St. Louis, May 6-10, 1946; Eng. News-Record, **136**, No. 22, 56 (1946) May 30.

Two methods used in plants where corrosion in water system is a problem are discussed: calcium carbonate scale treatment and deaeration. The former causes trouble sometimes because the calcium carbonate deposit is heavier than the corrosion product would have been, and is not of the right type to seal off the metal surface. Corrective methods include: (1) avoidance of use of water contaminated with turbidity, oil or inhibitors; (2) chlorination to oxidize organic inhibitors and eliminate algae and slime; (3) omission of phosphate salts and organic compounds; (4) proper selection and

feeding of chemicals. Inhibitors are not practical where flow is extremely large. Vacuum deaeration is particularly adaptable in these cases. Costs are compared.

**Metal Corrosion by Water and Steam.** W. MURRAY, Chem. Trade J. & Chem. Eng., **117**, 247-249; Discussion pg. 249 (1945) Aug. 31. Cor. & Mat. Prot. **2**, No. 8, 28 (1945) Nov.

Deals with causes of electrolytic corrosion; some typical instances and methods of inhibition; principles of water treatment for cooling and heating systems, boiler-water feed lines, cast-iron economizers, boilers, and steam and condensate lines; removal of carbon dioxide; and possibilities of natural protective films.

**Water Conditioning is More Engineering Than Chemistry.** L. F. COLLINS, Heating, Piping & Air Conditioning, **18**, 86-88 (1946) May.

Over 20 years of experience in the field of water conditioning has demonstrated to the author that recurrent troubles are more often the results of misapplication of the art of treatment than of voids in the science of water chemistry; and that errors in the art of treatment usually stem from unwarranted attempts to economize on first costs, and to inadequate instruction of operators, or both. He stresses in this article the necessity for making preliminary studies, supplying adequate capacity and operating guides, and for housing treating equipment in places where intelligent operators will work. It is also stressed that operators should be instructed more in detail than is required merely to conduct routine tests, and that all



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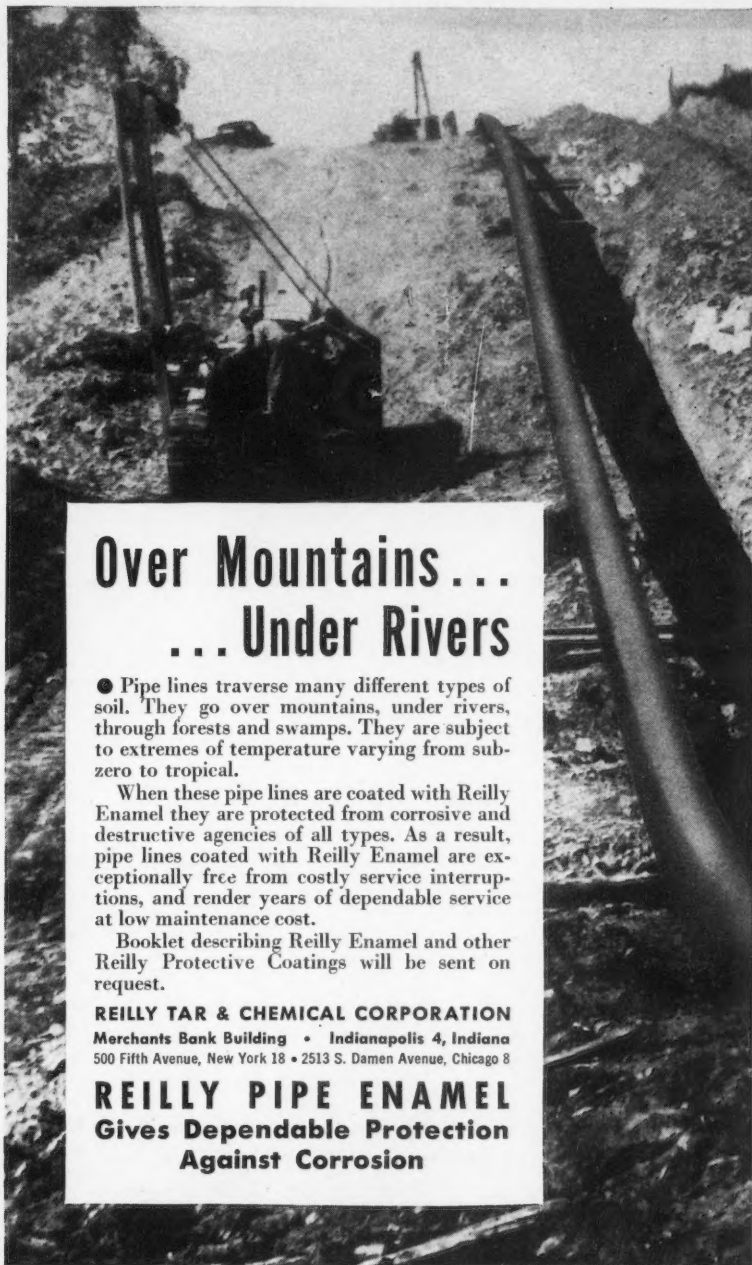
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### **Corrosion in the Water Industry.**

H. A. PRICE, City of Los Angeles, Dept. of Water & Power, Corrosion, 2, No. 2, 95-100 (1946) June.

Problems in the water-works field include: water meter corrosion, corrosion in service lines between street main and meter, cavitation in pipe lines immediately downstream from gate valves used for throttling purposes, graphitization, and galvanic corrosion. The work of the Electrolysis Section of the L. A. Dept. of Water and Power is described. It includes engineering surveys of soil corrosivity, stray current electrolysis, and any and all factors contributing to corrosion of underground pipe-lines and water-works plants; preparation of recommendations; corrosion prevention or mitigation and preparations of specifications.

**Cooling Water Treatment for Internal Combustion Engines.** Treatise by Mutual Chemical Co. of America, Diesel Power & Diesel Transportation, 24, No. 5, 578-582 (1946) May.

Corrosion in cooling systems of internal combustion engines through damage to cast iron cylinder blocks, can be only reduced by water treatment, since nature of water passages are such that protection by painting, plating, etc. is impossible. Chromate protection, and control of bi-metallic corrosion between radiators of copper brass and other nonferrous metals and iron of cylinder blocks, are discussed.

